USING ECOLOGICAL DYNAMICS AND EXPERT KNOWLEDGE TO EXPLORE EXPERTISE-APPROPRIATE PRACTICE PEDAGOGIES FOR THE TAEKWONDO ROUNDHOUSE KICK

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ABSTRACT

Using a taekwondo skill, this thesis presents the application of ecological dynamics to technical coaching that may help in adapting to rapid developments in rules and technology. The thesis also demonstrates a framework for using the coaching-biomechanics interface to reveal knowledge that will benefit both coaches and researchers. The coaching-biomechanics interface seeks to integrate coaches' experiential and researchers' theoretical approaches to identify and solve the same problem. While the framework in this thesis builds on the literature on the coaching-biomechanics interface, it could potentially guide knowledge creation and dissemination in other fields. To this end, the research was designed with three studies that flowed into each other. First, the first study presented in Chapter 3 aimed to capture expert taekwondo coaches' experiential knowledge of the critical variables that determine an effective roundhouse kick. Specifically, the coaches provided information on the variables they thought would contribute to scoring kicks in competition and those that would distinguish between intermediate and expert performers. The secondary aim was to evoke the coaching-biomechanics interface and translate the coaches' knowledge into observable biomechanical variables for future investigation. The final aim was to elicit further expert knowledge to assess the usefulness of the resulting variables. The study presented in Chapter 4 examined expert-intermediate differences in the coach-identified and researcher-translated critical variables to verify their usefulness in determining expertise. Three-dimensional measurements were made on intermediate and expert participants while performing the kick in varying levels of representativeness, all of which are routinely used in taekwondo practice. To further increase representativeness, the participants kicked a live target (the author) who was wearing the competition approved body armour, and kick effectiveness was determined by the scoring average on the armour. Finally, the study presented in Chapter 5 investigated the effects of a six-week representative learning intervention in terms of the coach-identified and researcher-translated critical variables and kick effectiveness. A case-series design was used in which multiple single-subjects were observed. Comparisons were made to expert coordination from Chapter 4 with respect to variability changes in the front knee angle at cut, the front knee angle at kick, and the interpersonal distance at the cut between levels of representativeness.

In Chapter 3, six higher-order themes emerged from interviews of four expert taekwondo coaches: (1) hip flexibility, (2) balance, (3) control/coordination, (4) distance, (5) footwork, and (6) speed. These were supported by several sub-themes. By using the coaching-biomechanics interface, the authors translated each theme and sub-theme into biomechanical variables based on existing research and potential usefulness to coaching: (1) front knee height, (2) support foot balance, (3) foot velocity, (4) interpersonal distance, and (5) cut-kick transition speed. Two separate expert coaches appraised these variables in terms of understanding, importance, coachability, and differences in expertise.

Results shown in Chapter 4 that variability in the normalised knee angle at the cut reduced when a target was present (F (2, 18) = 6.09, p = .010, η_p^2 = 0.404). Similarly, the variability in the normalised knee angle at the kick dropped considerably in the presence of a dynamic target (F (2, 18) = 4.28, p = .030, η_p^2 = 0.323). Experts had greater variability than intermediates with respect in IPD at

the cut (F (1, 9) = 7.386, p = .024, η_p^2 = 0.451). These variables' marginal significances and moderate effect sizes were taken as evidence of interaction and formed the basis for an expert model that may reflect responses to applied pedagogy in the following study.

While no pre-post differences were found in the observed variables as part of the study presented in Chapter 5, the limited implementation of the learning intervention appeared to result in emerging expert coordination patterns in the interpersonal distance at the cut. Although the changes in coordination did not produce clear immediate or lingering post-intervention scoring improvements, elements of this study's learning intervention could easily be adopted to coaching practice and future research.

With an ecological dynamics framework, this thesis used a more representative research design to examine a model for the coaching-biomechanics interface. Taken together these studies support the use of expert coach knowledge as a device for analysis and communication between sport scientists and coaches. These conclusions are however limited by the availability of relevant expertise, which in turn left several results underpowered. Much has been learned about taekwondo from this thesis, some of which may be generalised to other combat sports. However, the author would like to highlight the coaching-biomechanics interface, the fruitful collaboration between researchers and coaches, an approach that hopefully inspires more efforts to close the gap between research and practice.

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Bercades, L. T., Oldham, A., Lorimer, A., Lenetsky, S., Millar, S.-K., & Sheerin, K. (2022). Experiential knowledge of expert coaches on the critical performance factors of the taekwondo roundhouse kick. Submitted to the International Journal of Sport Science & Coaching on 18 January 2022.	Bercades: 85% Oldham: 5% Lorimer: 5% Lenetsky: 2% Millar: 2% Sheerin: 1%

Chapter 4

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Chapter 5

Bercades, L. T., Oldham, A., Lorimer, A., Millar, S.-K., & Sheerin, K. (2022). Using ecological dynamics to explore expertise-appropriate learning design for the taekwondo roundhouse kick. A case-series. In final preparation for submission to the International Journal of Sport Science & Coaching.	Bercades: 85% Oldham: 5% Millar: 4.5% Sheerin: 4.5% Lorimer: 1%

We, the undersigned, hereby agree to the percentages of participation to the chapters identified above:

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ATTESTATION OF AUTHORSHIP

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which to a substantial extent has been accepted for the award of any other degree or diploma of a university or other institution of higher learning, except where due acknowledgement is made in the acknowledgments.

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CHAPTER 1

BACKGROUND, RATIONALE AND SIGNIFICANCE OF THE STUDY

1.1 Background

The ecological dynamics approach to learning views the acquisition of skill as a result of interactions between learners and the environment. During these interactions, each learner perceives the environment based on his or her individual characteristics and capabilities. As skill progresses, the learner better attunes to the variables relevant to successful performance.[1] Exploiting these variables to regulate performance forms the foundation of ecological dynamics. This approach is an alternative to enrichment theories of learning, wherein environmental stimuli are unclear, and learners find solutions through inferential processes or internal knowledge structures.[1]

A continuing challenge among coaches is to recognise key variables or constraints to manipulate in order to create purposeful behaviours.[2] Constraints regulate the interacting parts within the complex system of motor skill acquisition.[3] Practitioners need to design practice sessions integrating these constraints to best represent the performance environment, and in doing so, will better simulate the performance environment to produce more functional movement solutions from the learner.[4] Additionally, learning designs should be appropriate to the skill level of the learner, and should be adjusted as the learner progresses or the complexity of the task changes.[3] Pinder et al.[5] offered a framework that combined Brunswik's concept of representative research design[6] and Gibson's ecological psychology.[7] The representative learning design framework emphasises tasks that preserve the environment-learner information sources for better skill transfer. Representative information sources such as appropriate movement speed, and the presence of a teammate or opponent assist in achieving movement responses and decisions suitable in the performance context.[5] Research supporting this framework has demonstrated different movement coordination between sports tasks with, and without, key ecological constraints. [8-10]

Combat sports such as judo, taekwondo, and boxing offer a rich context for studying dynamic skills as they involve a complete dyad that may be simplified for study.[11] They are also Olympic sports that may reflect a broad scope of expertise, so that comparisons of critical skill variables between expertise levels may be beneficial. Although uncommon, some research has preserved key information-movement couplings while observing certain performance variables and may be fertile ground for more study.[12-14] Lastly, it may be argued that these sports are deeply grounded in instructional or traditional models of learning;[11, 15] therefore, presenting a valuable opportunity to explore and compare these models to more representative learning designs.

Taekwondo is a traditional Korean martial art that emphasises striking with the hands and feet. Taekwondo has become very popular as a combat sport because of its exposure in the Olympic Games—first as a demonstration sport in the 1988 Seoul Games, then as an official sport in the 2000 Sydney Games. The World Taekwondo (WT) is the international governing body for the sport, boasting 209-member nations and more than 80 million participants.[16, 17] The WT, along with the *Kukkiwon* (World Taekwondo Headquarters), organise and unify taekwondo curriculum, standards, operation, and competition events.[16] From the 1970s onwards, taekwondo was developed into a competitive sport with the goal of its inclusion in the Olympics.[18] Early adoption of full-contact fighting, prohibition of punches to the head, and a large open competition area allowed the prominence of kicking techniques over punching in competition.[18, 19] Rules are continuously revised in response to audience feedback, judging transparency issues, and safety concerns necessitating frequent adjustments of techniques and tactics.[18] Unlike many competitive combat sports, fighters accumulate points by striking their opponent's torso, which is covered with an instrumented body armour known as the Protector and Scoring System (PSS). The PSS armours have sensors in limited areas as denoted by silver dots, requiring high accuracy to hit them (Figure 1.1).

Figure 1.1: ***Daedo TK-Strike Protection and Scoring System Body Armour***

The roundhouse or turning kick to the torso (*dollyeo-chagi*) is the most common attacking technique in taekwondo competition[20] and has been studied rigorously. However, the majority of this research controlled and/or manipulated variables to better observe key factors of performance.[21, 22] While this systematic research design[6] increases the ability to pinpoint the exclusive effects of one independent variable, it also limits performer-environment interactions naturally found in competition and training settings. In keeping with Brunswik's[6] framework, there have been recent moves to design experiments that add more representative constraints from the performance environment that provide information to the resulting movement coordination. For instance, Roosen and Pain[23, 24] observed some aspects of performance during a combination of three alternating roundhouse kicks performed at what were described as "normal" (i.e., training maximum execution) and "100%" modes (i.e., competition maximum execution). An opponent held kick pads and moved in coordination with the attacker. Prior to this, most research protocols involved participants untargeted kicking, kicking a static target, or executing single kick repetitions. In providing a more representative task and environment, expertise would be more accurately demonstrated.[25] Observing the critical variables of the roundhouse kick using a representative research design will build on the data from studies that used a more systematic design, providing knowledge that may be more applicable to practitioners.

For skill acquisition, practitioners need to know the critical variables of each technique on which to focus their efforts.[26] These critical variables are related to the efficient and effective performance of a movement.[27] More precisely, a critical variable indicates the qualitative features of a movement's coordination pattern,[26] and expert knowledge has been sought to isolate these variables.[28-30] Noteworthy were the variables that experts found difficult to describe. For example, coaches used the term “look and feel” of a technique, implying a holistic perception of the action, instead of specifying isolated variables. Moreover, coaching judgments were made based on these perceptions.[31] There were also variables that were not supported by the research at the time.[29, 32, 33] Only one study was found on taekwondo that used coaches' verbal reports to identify the key variables of the roundhouse kick.[34]

There have been efforts to integrate expert coaches' knowledge to strengthen theory or drive research questions in coaching practice.[35, 36] The term “coaching-biomechanics interface” has been used to describe this collaboration.[35, 37] The coaching-biomechanics interface begins with the coaches' knowledge, which is then combined with scientific concepts, to help explain the sports technique. Increased interaction with coaches may inform scientists of the specific problems or areas that are important to coaches. Closing the gap between researchers and practitioners will enhance both knowledge transfer and knowledge creation.[38] In the first instance, capturing expert knowledge in a meaningful way is essential and there has been previous work in acquiring expert knowledge in a representative manner.[28, 37] In these works, interviews were supported by activities commonly made by coaches, such as video analysis and observation of coaching sessions.

Another strategy in identifying critical variables in movement coordination research is comparing different levels of expertise. Research by Temprado et al.[26] investigated various joint couplings during the volleyball serve to determine if expertise relates to a clear distinction between stages of learning wherein the values of the critical variables were statistically different between novices and experts. The intra-limb coordination between the elbow and the wrist emerged as the candidate critical variable in this research, but instead of a clear disparity between novices and experts, there was a succession of coordination states distinguishing between expertise groups.[26] That is, the coordination pattern of the experts occurred among the novices, although at a low frequency. In contrast, the novices' coordination pattern endured among the experts.[26] Subsequent studies that have made expertise-based comparisons on critical variables of sport skills have yielded inconsistent results.[39, 40] Based on the variability in past research, the strategy of using expertise to uncover critical variables may be better reinforced by expert knowledge to identify those variables which would be the most useful to practitioners.

Observing changes in critical variables of the taekwondo roundhouse kick by manipulating constraints would yield valuable knowledge for practitioners. However, research written in English on constraints-based skill acquisition in combat sports is not very common. One possible reason for this lack is that combat sports are mostly based on traditional martial arts. Learning in martial arts could be characterised as improvement of inferential processes, or internal knowledge structures, that enrich stimuli that lack information from the environment.[1] This is exemplified by repetitive training to reproduce an ideal model of performance known as forms training.[41] Forms are standardised sequences of techniques performed individually or in a dyad performed in a standardised context (i.e., choregraphed, noncombative). Learners are meant to master the techniques without any individual variations, and variations are only allowed when they have been judged experts.[41, 42] Alternative to this rote repetition, ecological dynamics sees motor learning as a continuing process of solving a motor problem by changing the technique from repetition to repetition, in which “practice is a particular type of repetition without repetition”.[43]

Some combat sport research looked at skill acquisition in the light of ecological dynamics. The learning of a judo throwing technique was compared between traditional methods and more representative ones and found that representative practice tasks improved movement pattern and global performance as well as produced superior performance at retention and transfer.[11, 44] In these studies, technique performance was compared between static traditional practice and other methods of increasing representativeness (i.e., more dynamic and actual throwing of the opponent). Research on the acquisition of striking techniques in combat sports is even more difficult to find. Hristovski[45] studied the effects of a constraints-based training programme in a case study of a novice learning the rudiments of boxing. Here, a body mannequin was moved irregularly in different directions to help establish the coupling between the scaled distance and punching efficiency. This dynamic presentation of the target progressed to pad work and then to situational sparring. Kim[46] found changes in segmental velocity and kicking leg pattern in novice participants learning the taekwondo roundhouse kick on a static target after a five-week practice period. No model and no augmented feedback were provided to the learners, but foot velocity and accuracy results from previous sessions were presented. From these encouraging results, opportunities are plentiful to study the effects of constraints-based pedagogical methods on critical variables and performance outcomes of taekwondo techniques, especially those used in dynamic competitive contexts.

In summary, there are rich prospects in discovering critical variables from expert taekwondo coaches. A representative experimental design seeking expertise-related differences may provide a more accurate indication of the importance of these variables to the taekwondo roundhouse. Knowledge garnered from both coaches and representative experimentation could inform a more representative and individualised learning design that may help taekwondo coaches and competitors adapt more quickly and effectively in competition and to rapid changes in rules.

1.2 Rationale and Significance of the Research

Despite the biomechanical research on the taekwondo roundhouse kick, additional light can be cast in the context of ecological dynamics and expert knowledge. This thesis attempts to build on the previous work using the coaching-biomechanics interface, seeking to integrate context-driven expert knowledge and researchers’ search for generalisable truths. Likewise, the research presented herein uses representative design to arrive at results that are more useful to practitioners, effectively closing the loop of the coaching-biomechanics interface. Applying this shared knowledge, along with concepts of ecological dynamics, to researching and learning taekwondo skills will complement the traditional approach, especially in this time of great flux in competition rules. The intention is that the findings from this research will help researchers and coaches work closer, integrating scientific principles with the nuances of coaching for an enhanced learning experience for fighters. While this research is targeted at the roundhouse kick, the principles uncovered may provide a platform for coaching and learning in other taekwondo movement tasks.

1.3 Statement of the Research Problem

The overall aim of the thesis is to use the taekwondo roundhouse kick to help understand how expert knowledge can be used to identify critical performance variables, and to then understand how to teach those variables. To achieve that aim, the thesis is designed as three studies that flow into each other. The first study will acquire expert knowledge in a representative manner to determine the critical variables that influence an effective roundhouse kick as used in competition. The second study will study the candidate variables from the previous study to determine their importance in determining kicking success while adhering to a representative research design resulting in more meaningful generalisations for taekwondo performance. Finally, the primary aim of the third study is to design and implement a representative learning design based on expert knowledge and ecological dynamics, and then to evaluate the design by detecting any changes in the critical variables and their effects on kicking performance. The objectives of each study are described below:

The study presented in Chapter 3 aims to answer these questions:

1. What do expert taekwondo coaches perceive as the critical variables of an effective roundhouse kick?
2. How can the coaching-biomechanics interface be applied to translate expert knowledge into observable biomechanical variables for future use?
3. How do expert coaches perceive the usefulness of the resulting biomechanical variables to coaching?

The study presented in Chapter 4 aims to answer the following questions:

1. Are there expertise-related differences in the critical variables identified by the experts and translated into biomechanical variables from the first study?
2. Are these differences more pronounced when the kicking conditions are more representative of the performance environment?
3. Are there expertise-related differences in variability within the observed variables?
4. Are the differences in variability more distinct when the kicking conditions are more representative of the performance environment?

The study presented in Chapter 5 attempts to address the question:

1. How will a practice strategy based on expert knowledge and ecological dynamics affect the critical variables and kicking performance in intermediate taekwondo athletes?

1.4 Thesis Structure

This thesis is presented in a manuscript structure that combines chapters on the introduction, literature review, and general discussion of the whole project. There are chapters based on articles that have been submitted for publication or are in the final process for submission. As the article-chapters are intended to be stand-alone chapters, repetitions of concepts and references may be found here to improve readability.

Chapters 1 (Background, Rationale and Significance of the Study) and 2 (Review of Related Literature) present the foundation for the entire thesis and set up the flow of the following chapters. Chapter 3 explores expert knowledge on the critical variables of taekwondo roundhouse performance and how these were translated to biomechanical variables. Chapter 4 assesses the candidate critical variables by detecting expertise-related differences in kicking conditions of different levels of representativeness. Chapter 5 presents and evaluates a learning intervention based on expert knowledge and ecological dynamics. And finally, Chapter 6 provides a general discussion, practical implications, limitations, and future directions (Figure 1.2).

Chapter 1 Background, Rationale and Significance of the Study
Chapter 2 Review of Related Literature
Chapter 3: Study 1 Experiential Knowledge of Expert Coaches on the Critical Performance Factors of the Taekwondo Roundhouse Kick
Chapter 4: Study 2 Expertise-related Differences due to Increased Task Representativeness for a Taekwondo Roundhouse Kick Combination
Chapter 5: Study 3 Using Ecological Dynamics to Explore Expertise-appropriate Learning Design for the Taekwondo Roundhouse Kick. A Case-series
Chapter 6 General Discussion, Practical Implications, Limitations, and Future Directions

Figure 1.2: ***Structure of the thesis***

CHAPTER 2

REVIEW OF RELATED LITERATURE

This chapter reviews research to provide a theoretical background on the three studies in the thesis. The main sections support each of the studies, with the subsequent sub-sections narrowing the focus on the specific topics of interest for each study. The first section focuses on expert coaches' knowledge, with particular reference to the characteristics of effective and expert coaching, the process and sources of the knowledge that makes coaches effective, recommendations to enhance coaching knowledge and practice, and examples of expert coach qualities and how these differ with novice coaches. The second section highlights some of the critical factors of the taekwondo roundhouse kick previously observed in the laboratory, the differences between expert and novice fighters, and examples of research protocols used to observe the kick. The final section highlights works on the foundations of ecological dynamics, with a focus on constraints and representative learning design, and learning in martial arts and combat sports.

2.1. Coaches' Knowledge

2.1.1. Effective Coaching

In the ecological dynamics approach, coaches are seen as designers of learning environments that allow athletes to take advantage of learning opportunities that encourage adaptive performance behaviours.[47, 48] Key to this process is the coach's ability to identify and manipulate essential constraints of the practice environment to guide the perception and consequent actions of athletes. Also important is the coach's ability to collaborate with the athlete and the rest of the coaching team to design the practice landscape.[48] Nonlinear pedagogy provides a framework for these tasks and Chow[49] stressed the following principles for learning design: (1) representative learning design, in which learning contexts simulate essential aspects of the performance environment that learners can use as information to regulate their actions; (2) developing appropriate information-movement couplings, where learners develop behaviours from their perception of the environment; (3) manipulation of constraints that are relevant conditions that facilitate the discovery of functional movement solutions; (4) accounting for inter- and interpersonal functional variability during exploratory learning; and (5) reducing external attentional focus to exploit self-organising processes.

For coaches to design effective learning environments, they should initially have sufficient diagnostic abilities to identify performance behaviours that need to be improved and which constraints are appropriate to manipulate.[47] Expert coaches have been found to have more advanced diagnostic skills than novice coaches.[28, 50] Expert coaches were able to see the tennis serve as 'a whole' compared to novices who focused more on isolated elements.[50] Expert volleyball coaches were able to describe the volleyball spike in greater detail than novices, identifying critical components using more anatomical terminology.[28] The challenge for coaches is to choose key constraints for individuals and how to manipulate these constraints that would encourage learning.[47]

Effective goal setting allows the coach and the learner to direct the attention to relevant activities and allows a collaboration that can increase motivation to learn.[51] Goals must be representative, individual and nonlinear in approach that would promote the discovery of functional solutions in performance contexts.[47] Some coaches may not be aware of the significance of the processes around goal setting. For instance, while female amateur team sport players perceived that their team's set collective outcome, process and performance goals, and that these goals were recorded, they also indicated that only some of the goals were evaluated at the end of the season.[52]

Coaches advocating nonlinear pedagogy must be well versed in task simplification in the design of practice environments.[47] In contrast to task decomposition in which individual components of the task are practised in isolation, simplification retains the 'coherence' of the task while retaining the action-perception coupling.[4] Clear technical goals should be set and constant feedback from the learner is solicited when designing simplified tasks as exemplified in a case study of a para-athlete learning specific technical factors of the high jump.[53] Along with the athlete's disability, other key organismic constraints may be considered, such as their emotions (e.g., concerns over landing), when simplifying tasks.[53]

Coaches must be skilled in constraints manipulation that result in stable movement patterns over time but at the same time be adaptable to changes in the performance context.[4] For example, elite divers were encouraged to avoid balking (abandoning dive attempts that they did not perceive to be 'ideal') during their practice dives.[9] After the 12-week learning period, this simple task constraint allowed the divers to adapt their movement patterns and stabilise performance outcomes. An environmental constraint was altered to assist the learning of a disabled high jumper by moving their practice jumps from the field into a gymnastics area to exploit the relative safety of the sprung floor and foam pit.[53] When considering organismic constraints, constraints that limit learners from displaying their skill (called rate limiters) must be taken into account.[47] In this case, equipment and space may be scaled to compensate for a young learner's lack of strength or power that may affect the desired movement pattern.[47] Decisions on constraints manipulation must come from a careful performance diagnosis and close collaboration with the learner.

In addition to relevant constraints manipulation, coaches must ensure that these occur in practice contexts that are representative of the actual performance environment to preserve useful perception-action couplings.[6, 47] Elite field hockey coaches used game-centred learning in practicing field-goal shooting, which reflect representative learning design. Small-sided games were the highlight of this approach in contrast to drills in closed-skill contexts.[54] Cooperating with learners in designing practice tasks (termed representative co-design) could encourage psychological engagement, a greater sense of ownership, while increasing their knowledge of the performance environment.[55] Coaches would need great skill in interpersonal communication to maximise this type of collaboration.

Coaches who advocate nonlinear pedagogy must be adept at designing practice tasks that encourage the adaptive variability of the learner. Practice should promote the discovery of different ways to achieve the same task goal, and the exploitation of the use of the same solution for different problems.[47] Traditional approaches prescribe a 'criterion model' for the desired skill that learners are meant to adhere to without contextualising it to relevant constraints.[56] To exemplify the reinforcement of adaptive variability in boxing, the learner was constrained to a parallel stance to provide equal opportunities for both arms to increase the emergence of left- and right-arm punching combinations.[45]

On the other hand, boxing purists typically teach punches from a diagonal stance that limit the variability of potential movement solutions.

In this section, effective coaching was framed within an ecological dynamics approach. Coaching competencies were discussed within a nonlinear pedagogy framework and examples were presented and contrasted with traditional methods of learning. The next section presents some sources of coaches' knowledge.

2.1.2 Coaches' Knowledge and its Sources

Coaches are tasked with making reliable and accurate observations of the athlete's technique in order to make a judgement, and subsequent guidance, to maximise the performance within effective coaching sessions.[37] It is assumed that coaches have the appropriate technical and pedagogical understanding to successfully guide the performer. Irwin et al.[57, 58] outlined a number of sources reported by coaches on the origins of their technical knowledge. Coaches identified mentor coaches as the most important resource for their knowledge. Trial-and-error experimentation was rated the second most important source of gaining understanding. However, the coaches identified inadequacy in theoretical knowledge resulting in trial-and-error experimentation that may result in inefficient preparatory activities in skill progression. Past experience as a performer was also cited as an important factor. Interestingly, the coaches suggested that performers who were less naturally gifted developed stronger analytical skills to compensate for their limitations; thus, transitioning better into coaching. How coaches expand on their existing knowledge was also discussed within the same studies.[57, 58] Within this domain, coaches referred to the use of coaching manuals, coaching videos and videos of experienced performers. Interaction with sport scientists was also mentioned, although it was acknowledged sports-specific knowledge was required for this support to be useful.

Another factor that influences the coach's mindset is refinement of known techniques.[57, 58] An illustration of this process can be found in the sport of taekwondo, and the modification of taekwondo kicking techniques over the years, as traced by Moenig.[18] As an example, prior to 1967, the ball of the foot was the contact point of the roundhouse kick in point sparring, providing only light contact on an opponent. However, full-contact competition began that year, and rapidly the point of contact switched to the instep. Reasons for this change were the greater incidence of injury to the toes, greater kicking speeds, and a more audible sound on the body armour (*hogul*). Over time, the sound on the *hogul* became an indicator for scoring a point. Kick execution progressed further from a wide arc to a straighter and more forward direction. After the 1988 Seoul Olympics, the relatively low scoring competitions prompted judges to award more points to kicks with light contact or impact. The direct result was a faster, but less powerful roundhouse kick. Another major shift in the rules happened prior to the 2012 London Olympic Games, where the electronic body protector (EBP) was introduced. Modelled on the fencing scoring system, the EBP sought to enhance scoring transparency. The threshold force needed to score points on the EBP has also undergone progressive change, necessitating constant technical modification of the scoring kicks.[19] In the case of the taekwondo roundhouse, technical coaching requires rapid refinements that adapt to the task constraints of rule changes.

The coaching-biomechanics interface has been proposed to exploit the coaches' experiential and biomechanists' theoretical knowledge. Past research form the basis of the coaching-biomechanics interface, which aims to understand and inform coaches' knowledge about their technical analysis of a performer's technique.[37] The coaching-biomechanics interface starts with the coaches' knowledge, gleaned from interviews or observations, combined with grounded scientific concepts, which help to understand sports technique.[35] Irwin and Kerwin[35] highlighted this approach while examining an artistic gymnastics skill. Official changes in bar spacing for the uneven bars event allowed female gymnasts to perform different variations of the common release and regrasp skill, the Tkachev. The modification brought to light issues on scoring (i.e., should both versions be valued with the same level of difficulty?) and training (i.e., do both versions have the same technical and physical demands?). From this coaching dilemma, an investigation was conducted to quantify the differences in musculoskeletal work between the outward and inward versions. Musculoskeletal work was found to be mostly positive in the outward variation, and negative in the inward variation. Thus, the inward version provides more opportunity to produce more complex versions of the skill through changes in body shape during flight. However, training must include specific preparatory activities that more closely resemble the skill to elicit appropriate musculoskeletal adaptations. The authors emphasised the need to close the knowledge circle and find ways for researchers to effectively convey the information back to the coaches in a meaningful way.

Despite some successful cooperation between coaches and researchers, coach-to-coach communication has been acknowledged as the most common way to transfer knowledge. In a study involving university-based coaches,[38] the investigators specifically looked at how coaches perceived sport science research, what sources they consult when looking for new ideas, and what barriers they encounter when seeking new information. While respondents believed that sport science could provide new ideas to improve their practice, and that research is being conducted to benefit their sport, they preferred to consult other coaches for advice. This form of knowledge transfer has the potential to replicate existing practice at the expense of novelty and/or critical analysis. If the coaches did use sport science information it was mostly through attending seminars, and personal contact with sport scientists, which are considered unmediated learning processes. They preferred personal contact to reading journal articles and databases. The authors concluded that this latter type of information-seeking process would not be conducive to effectively use sport science, which takes time and expertise to sift through the literature. These findings further highlight the divide between coaches' practical knowledge and theoretical information. Similarly, the coaches in Williams and Kendall's[59] study preferred attending workshops, networking, and reading sports-specific magazines to seek out knowledge. However, researchers who were interviewed emphasised reading scientific journals, networking, and attending conferences. Both coaches and researchers agreed that 'there was a need for sports science researchers to translate scientific journals into easily understood language'. As such, researchers may need to consider multiple forums with different levels of language to present their research. Both groups rated 'good rapport' as the most valued quality in coaches and researchers, suggesting an acknowledgement of the supportive relationship between the two groups. But, at the same time, it may present an area for improvement as most coaching programmes give little time for interpersonal skills.

Williams and Kendall[59] investigated a possible gap between researchers and coaches. The investigators surveyed elite coaches across a range of sports and researchers in Australia on the perceived research needs of elite coaching practice. The coaches rated ‘mental preparation of athletes’ as the most important, while the researchers rated ‘development of recovery techniques for athletes’ as higher priority. Several survey items touched on the way research topics ‘are determined’ and ‘should be determined’. Both coaches and researchers ranked ‘together the coach and researcher should determine the question’ highest. However, in responding to how research questions ‘are determined’, the researchers ranked ‘the scientist alone raises the question’ first, while the coaches ranked ‘together the coach and the researcher should determine the question’ first. This perceived collaboration by the coaches might indicate that they are only aware of the research developed by this approach.

As highlighted previously, coaches feel that the knowledge gained from experimentation or trial-and-error may originate from an insufficient understanding of the theoretical foundations of successful performance. An experimentation process may bring about inefficient preparatory activities towards skill progression and may also restrict the sharing of information across coaches and between coaches and researchers. Differences in terminology play a big part in this miscommunication as evidenced by terms used in coaching literature but rarely used in biomechanical literature.[60] The situation can be aggravated by the coaches’ low regard for consulting sports scientists. [57, 58] In this respect, discussions on the ‘knowledge-practice’ gap or enhancing ‘evidence-based practice’ have been gaining prominence. To address the divide between coaches’ practical knowledge and theoretical information, Reade et al.[38] suggested establishing institutional expectations for coaches to constantly innovate their programmes based on sport science evidence. It was also proposed that sport scientists make more efforts to increase their accessibility to coaches. Increased interaction with coaches may inform scientists of the actual specific problems or areas that are important to coaches. Reducing the gap between coaches and researchers will improve both knowledge transfer and knowledge creation by developing research questions in tandem.[38]

Coaching style and level of coaching may also be factors in coaches’ attitudes towards knowledge seeking.[51] Collins[51] examined the beliefs and attitudes inherent in judo coaching, and discovered that most coaches believe that the autocratic coaching style is appropriate for novices. The results indicated a possible complacency in knowledge seeking at the club level that may be brought about by the definite content of the judo syllabus, the perceived effective coaching style to teach it, and the coaches’ (both club and elite) and players’ attitude towards the structure and education required. Collins[51] recognised these gaps, and suggested that to be truly effective, judo coaches needed to enhance their own performance by learning new coaching-specific knowledge and engaging in critical self-reflection. Institutional measures were proposed, like introducing coach education to players as early as blue belt grade; starting specialised coaching modules for different weight categories, specialised skills, and sport psychology; and including overloading training methods that would simulate the physical and psychological loads of competition.

It appears that coaches prefer to gain knowledge via face-to-face interactions with other coaches instead of more formal avenues such as courses, reading journal articles, and attending conferences. There also seems to be a knowledge gap between researchers and coaches, something that is rarely capitalised on in research. Another factor that may affect knowledge-building, specifically in combat sport coaches, is the inherent autocratic coaching style within the predominantly traditional martial arts set-up. Lacking in the research is coaches' knowledge regarding the athlete-environment interactions. As with coaches, researchers could adopt an ecological dynamics approach by considering the performer-environment (or rather, researcher-environment) interactions when designing research. There is evidence that the coaching-biomechanics interface is a model of discovering and disseminating knowledge that may bridge the theory-practice chasm.

2.1.3 Expert Coaches' Knowledge

Previous research on expert gymnastics and sprint coaches use similar, general terminology to describe fundamentals, or the predominant technical constructs of a skill.[32, 58] To shed more light on the use of terminology, Grant, McGullick, Schemp, and Grant[61] examined expert golf instructors' fundamental content knowledge and the nature of fundamentals in sport instruction. Based on survey responses, participants were grouped into 'Elemental Instructors' and 'Compound Instructors'. Elemental Instructors had a consensus on the fundamentals of golf, while the Compound Instructors did not. Elemental instructors identified aspects that players should master in order to play golf (the grip, posture, and alignment). Compound instructors, however, used their own terms that involved multiple movements to be able to master the fundamentals. A possible reason for the discrepancy might be that the fundamentals are not skills; rather, underlying principles expressed in various ways. Compound instructors may also be better grounded in nonlinear pedagogy when they express terms in movements instead of components. A common vocabulary of the fundamentals of taekwondo would greatly aid communication between coaches and other coaches, and coaches and researchers.

Critical elements or features have been defined as important aspects of performance that are related to the efficiency and effectiveness of a movement[27] and coaches' knowledge of them has been collected. Sprint coaches' identified four higher-order constructs crucial to sprint running technique: 'posture', 'hip position', 'ground contact', and 'arm action'.[29] Except for arm action, the other constructs have basis in the literature. Other research reported expert constructs unsupported by literature.[32, 33] Additionally, some experts have difficulty describing technical constructs. For instance, Millar, Oldham, and Renshaw[31] found that rowing experts mostly used high order factors such as 'boat speed and efficiency', 'know when it looks right', 'know when it feels right', 'technique', 'timing', and 'catch' to describe critical factors in rowing performance. The experts had a difficult time consciously describing some of the constructs, which may suggest that skilled performance is perceived at the subconscious level. Likewise, there are aspects of expert knowledge not supported by research. Smith et al.[33] contextualised golf coaches' knowledge within the current biomechanical literature and found disagreements in the definition of the golf swing. Significantly, the most important events of the swing (e.g., initial downswing) as perceived by the coaches were not fully supported by research. From the gaps in research, greater integration of expert knowledge in research might improve applicability to practice.

Two studies that investigated coaches' technical knowledge involved sprint coaches' understanding of the phases of a race and the characteristics of good technique.[29, 32] The coaches broke down the sprint race into technical phases for specificity in instruction and feedback. While there was no consensus on the number of phases, there was agreement that a race should generally comprise of a start, middle, and an end phase. Some of the coaches' notions were supported by research, while others have not yet been investigated (such as the construct of 'relaxation' during the maintenance phase), indicating that coaches have important insight that could guide research.[32] Research on the taekwondo roundhouse[22, 62] has also used different terms to describe its events and phases. However, the investigators, instead of expert coaches, determined these. It is still yet to determined how coaches' perceptions will match up theory or can be measured in a mutually comprehensible manner.

Other studies have sought to explore the knowledge of expert coaches about the variables surrounding athletes and how athletes perceive them. Greenwood, Davids and Renshaw[63, 64] examined the understanding of elite track and field, gymnastics, and cricket coaches of the potential informational constraints that regulate the run-up task in these sports. Coaches in all sports mentioned locomotor pointing to the target on the ground (e.g., the take-off board in the long jump or the bowling crease lines in cricket) but none emphasised it as an important focus of attention. The coaches mentioned the importance of the athlete-environment relationship, particularly the athlete's dependence on the environment for perceptual information to guide his or her actions, and the use of actions to expose data on the environment. Coaches also observed that elite athletes could perceive differences between their current performance and the ideal skill, similar to coaches' knowledge of the skill schema.[28] Coaches also encouraged performers to be open to other sources of environmental information available to guide their actions. The coaches had an awareness that athletes perform differently in various task, individual, and environmental constraints, and that these constraints relate with one another. The challenge for coaches and performers is to distinguish between specifying (the ones that affect performance) and non-specifying variables (the ones that do not).[64] It has been suggested that coaches' knowledge can be a part of the identification of possible specifying variables in research to produce more meaningful results for both coaches and researchers.[64] In combat sports such as boxing, Hristovski, Davids, and Araújo[12] proposed that the target's 'reachability' (i.e., the interpersonal distance between the two fighters) was a likely perceptual variable to inform the attacker's decision to strike. The authors also suggested the influence of the perception of strikability, in which the attacker chooses the most effective strike (i.e., 'the intended energy of collision between the boxer's fist and target') depending on the reachability of the target. The research was replicated on taekwondo kicking techniques[13] but neither sought coaches' knowledge to verify these variables.

Focusing on a specific volleyball skill, Bian[28] examined the differences in the diagnostic ability between expert and novice coaches while analysing the spike. Verbal reports were used to collect data during three tasks: An initial interview asking the coaches to describe an ideal spiking technique and to list its components; a recall test following viewing of slides showing female players spiking; and analysis and diagnosis of spiking technique while viewing two video clips. Results showed differences in coaches' knowledge on the ideal spike in many aspects, such as the total number of components, body part vocabulary usage, the critical components identified in each skill execution phase, and the way coaches discussed skill execution and coaching. The experts' richer procedural knowledge may have afforded them greater analysis and diagnostic capacity. This type of knowledge, which comes from actual practice,[65] is enhanced by years of successful coaching experience. The experts' more detailed perceptual capability could have also helped with their better analysis, which should inform research design when collecting coaches' knowledge.

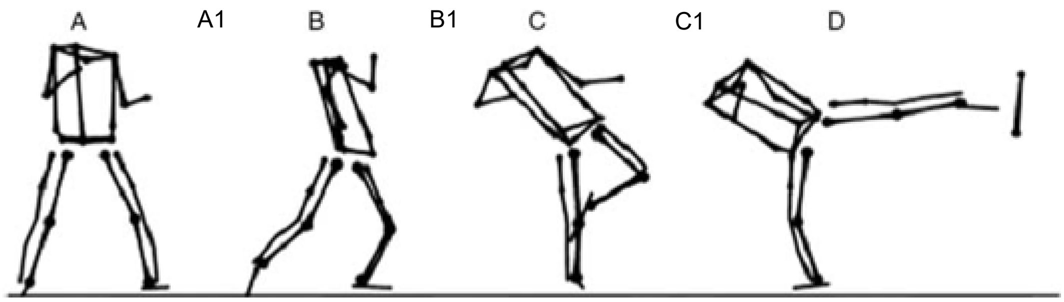
Bian's[28] representative research design that emphasised the normal technical analysis of coaches during performance deserves notice. By allowing coaches to analyse slides and videos, the researcher was able to enrich the interview data with knowledge from observation of performances. Representative design considers the ecological aspects of the phenomenon being investigated to establish the 'ecological generality' of a result.[6] Allowing coaches to perform their normal tasks in a representative manner may result in more valid insights than mere recall. This process is similar to the think-aloud method in which participants are instructed to focus on their tasks while verbalising their thoughts.[66] Another study implemented a similar design by observing and videotaping golf coaches as they coached a learner, and afterwards, conducting a semi-structured interview.[37] In so doing, coaches' knowledge was collected through direct perception and recall, preserving the perception-action coupling that is a defining concept in ecological dynamics.

In summary, it is clear that the vocabulary between coaches in some sport has limited consensus and thus, may thwart effective communication between coaches, between coaches and athletes, and coaches to researchers. Expert coaches in sports such as sprinting, rowing, and golf have been able to identify critical factors for success that have not yet been observed in research, as well as those they had difficulty verbalising. The knowledge of experts in athlete-environment interactions has not yet been fully captured, especially in striking combat sports. Research showing the practicality of the coaching-biomechanics interface is scarce. As such, more efforts to discover the experiential knowledge of coaches and athletes will surely uncover gaps in the knowledge of coaches, and a common language between practitioners and researchers agreed upon. The research reviewed here forms the foundation of a novel framework for discovering knowledge that puts coach knowledge on an equal footing with that of scientists. The interest will also most likely improve the relationship between coaches and researchers. Armed with these data, researchers and coaches could then together formulate research questions that could be more meaningful and applicable to those in the field. This partnership will advance knowledge exchange as research guided by coaches' knowledge is scarce. To this end, capturing expert knowledge in a representative manner may yield more generalisable results. Consequently, the first study of this thesis was designed to uncover expert coaches' knowledge on the optimal taekwondo roundhouse kick technique, to translate this knowledge into theory-supported critical variables for observation in the subsequent study, and to use expert knowledge again to assess the usefulness of those variables.

2.3 The Taekwondo Roundhouse Kick

The roundhouse kick was selected for observation in this current research as it is estimated to be the most frequently used technique in competition.[67, 68] The following review presents variables that may affect performance to assist in analysing and supporting the data derived from the coaches. It is essential to examine the current research to have a wide context to draw upon while trying to give meaning to the coaches' often different vocabulary. In addition, literature is presented to provide a background on the relationship of expertise to roundhouse kicking performance and the various kinematic and neuromuscular factors that influence it. Finally, a brief critique of research practices in the investigation of kicking performance is offered to support the representative approach of the present thesis.

The roundhouse kick (*dollyo chagi*) starts with a simultaneous rotation of the body on the support leg and the flexion of the kicking hip and knee. This is followed by external rotation of the hip joint, and extension of the knee of the support leg as the foot approaches the target.[69] The kick starts in the sagittal plane and finishes in the transverse plane because the target (usually the trunk or the face) has a surface perpendicular to the ground. The kick terminates at impact without a follow-through.[70] The multi-planar nature of the kick necessitates 3-D analysis for thorough evaluation. For ease of analysis, different studies divided the kicking movement into events and phases, which are summarised in Figure 2.3. These studies analysed the kick as executed from the back leg, which is different from the performance of the kick in this thesis. Nonetheless, these informed the analysis of the kick in the present thesis, specifically the hip/knee flexion and knee extension events (C and D in Figure 2.3).



Figure[71]

1) Kim, Kwon, Yenuga, and Kwon:[71] (A) Start; (A1) Push phase; (B) Toeoff; (B1) Release phase; (C) Maximum knee flexion; (C1) Striking phase; (D) Impact
2) Ha and Kim:[22] (A) Ready posture; (B) Maximum plantarflexion of the kicking leg; (C) Maximum hip flexion; (D) Impact
3) Wąsik:[68] (A) Ready posture; (B) Foot take-off; (C) Knee lift; (D) Knee extension
4) Pearson:[62] (B) Heel take-off; (B1) Period from B to maximum knee flexion; (C1) Period from C to impact; (D) Beginning of the impact; (E) End of impact

Figure 2.3 ***Events and Phases of the Roundhouse Kick***

To aid in characterising the roundhouse kick, kinematics of the ankle, knee, and hip have been described in both the kicking and supporting legs, as well as the motion of the trunk and centre of mass and are summarised in Table 2.1. Several studies also investigated the coordination of the roundhouse kick and are also condensed in Table 2.1. Coordination has been defined as the process of controlling redundant biomechanical degrees of freedom of a moving body.[46] Table 2.1 also presents some variables around unilateral balance to help describe kicking skill. It was difficult to find research on the correlation of single-leg balance on kicking techniques in combat sports. However, Chew-Bullock et al.[72] examined postural sway and centre of pressure coordinates and their correlations to ball kicking accuracy and velocity between the preferred and non-preferred legs. They noted that preferred leg kicking performance was associated with contralateral leg stability, but non-preferred leg was not. Some of these preceding studies related performance variables to outcome variables to signify the effectiveness of the kick. The outcome variables are discussed further below.

Table 2.1 ***Selected Kinematic Variables of the Roundhouse Kick***

Variables observed	Main findings
Joint angle ROM	Skilled athletes' trunks were more hyperextended than less skilled[22]
Joint ROM	Two different kicking styles: Type 1 had a noticeable knee flexion followed by a rapid extension before impact. Type 2 maintained a relatively straight leg.[73]
Joint ROM	Type 1 style found among Thai boxing, karate, and taekwondo fighters performing the high roundhouse to a target[74]
Joint ROM	Type 1 style found in a non-Olympic style taekwondo fighter performing the high roundhouse without a target[68]
COM	Similar forward movement between taekwondo and yongmudo fighters[75]
Intra-limb coordination	Among karate fighters, active control of the entire limb was the solution to the task requirement instead of controlling just the shank near the termination of the kick[76]
Time to peak velocity and segmental lag	Among taekwondo learners, significant change in roundhouse segmental velocity and kicking leg pattern after 10 practice sessions[46]
Inter-joint coordination (IIC)	The IIC discriminated coordination patterns between throw-like (i.e., hip flexion followed by knee extension) and push-like (hip and knee extension occur simultaneously) movements.[77]
Angular velocity ratio between segments (ω_{ratio}) and a normalised inter-segment timing index (t_i)	Among taekwondo fighters performing the roundhouse kick, as the target size increased, the ω_{ratio} decreased, indicating an increased joint stiffness, particularly at the knee. t_i also seemed to be target size-dependent, implying different coordination motor patterns used.[78]

Sway velocity of the COG and the foot centre of pressure (COP)	The variables tested unilateral balance and sensory system contribution to balance. Taekwondo practitioners had significantly slower body sway during non-dominant leg standing compared to non-practitioners. Long-term taekwondo practitioners had less reliance on visual input for balance than short-term practitioners.[79]
COP velocity	Used to compare postural balance between taekwondo athletes and a control group. The athletes had superior postural balance than the non-practitioners.[80]

Note: ROM: range of motion; COM: centre of mass

The following studies described various outcome variables that measure kicking performance. Estevan et al.[81] and Falco et al.[21] compared the execution time and impact forces of taekwondo roundhouse kicks at three different distances between medallist and non-medallist taekwondo fighters. They found that more skilled athletes had a shorter execution time at the short, compared to the long distance, while there were no differences among the less skilled ones. Since the medallists also elicited greater impact force at both distances, than did the non-medallists, execution technique may affect both factors. Foot velocity was specifically measured during the performance of the taekwondo roundhouse kick without a target,[68] with a target[62] and multiple kicks to a target.[23] Pearson[62] also assessed the linear velocities of the toe, ankle, knee, and hip of the kicking leg immediately before impact while executing a taekwondo turning kick. O'Sullivan et al.[75] investigated the angular velocities of the hip and knee as well as the maximum kicking foot velocity and kick phase times of taekwondo and yongmudo fighters. In one of the earliest studies of the roundhouse kick, Sidthilaw[82] investigated the Thai boxing variety and found a positive relationship between the mean final velocity of the kicking ankle and the mean peak force. Considering the different objectives of this fighting style, kick force seems to be more vital than movement speed in Thai boxing compared to taekwondo. Kick effectiveness in taekwondo research have been indicated by different outcome variables, although they may not represent the actual performance context as will be discussed later in this chapter.

2.3.1 Expertise-related Differences in Kicking Performance

Seifert et al.[2] framed expertise within the context of ecological dynamics. Within this structure, expert performance is accomplished as each individual discovers functional solutions to the interacting task, environmental and organismic constraints. Expertise relates to an individual's progressive adjustments to affordances in competition settings. Upon perceiving these affordances, experts have the ability to better exploit them and apply appropriate movement outcomes. As expertise increases, focus can be limited to the most suitable perceptual variables in different performance circumstances. This enhanced adaptability can then allow the learner to repeat the process of solving a motor problem more quickly by modifying techniques to changing constraints.[43] As expertise increases, adaptation becomes automatic as critical aspects of the movement solution become stable while allowing variability in others to achieve the intended outcome.[83] In taekwondo competition, expertise may be demonstrated by the effective observation of the important information in opponent's performance that results in successful adjustments to one's own technique.

Seifert et al.[2] suggested that one of the characteristics of expert performance is the stability of functional movement pattern coordination in relation to varying task and environmental constraints. This has been reported in relation to the performance of international- and national-class athletes in the execution of the karate *mae-geri* (front) kick.[84] The international-class athletes showed enhanced repeatability of inter-joint coordination than the national-class athletes. More experienced athletes also had faster movement times, specifically higher peak angular velocities at the hip and knee in both attack and return phases of the kick. Virdi et al.[85] found similar shorter total kicking times in elite taekwondo athletes performing the *dolgaechagi* (jumping-spinning roundhouse kick) as compared to non-medallists. It was assumed that the elite athletes had a more economical initial supporting leg swing that brought it more in line with the target. These results are similar to a study that compared the roundhouse kick between winners and non-winners.[86] While the execution times between participants of different skill levels were comparable, the winners' reaction times were faster, which resulted in a faster kick. The experts displayed stable performances in reaction times, execution times and impact forces from short and normal distances. On the other hand, the novices had more variable executions, implying the inability to adapt their technique to fluctuating constraints.

Moreira, Goethel, and Gonçalves[87] reported that the faster movement times exhibited by highly skilled taekwondo athletes were correlated with muscular activity and other kinematic parameters. They found that the interaction between agonist and antagonist muscles is a key factor of segment angular velocity, joint stabilisation during impact, and in the fine control of movement accuracy. Elite athletes also demonstrated faster pre-motor reaction times for selected muscles. The pre-motor reaction time indicated the speed of neural transmission and information processing. Additionally, the elite athletes displayed a higher co-contraction index of the muscles controlling knee extension (i.e., the agonists and antagonists). The higher co-contraction index may augment knee stability while hitting a heavy target, which supports the locking of the joints found elsewhere.[78] This pattern of muscle contraction is most likely due to adjustments to kicking more dense targets in practice.

The higher activation of the hamstrings was likewise found in another study comparing muscle activation between novice and advanced taekwondo-in executing the roundhouse kick.[88] The elite fighters' biceps femoris had a greater activation than the novices at the pre-impact phase and may have contributed to the deceleration and stability of the knee on impact. The participants kicked a static kicking shield held by a researcher; a target that offered more density and resistance to the kicks. This was likely a factor in the outcome that the soleus and rectus femoris muscles were less active in the advanced athletes during the same pre-impact phase. It suggests greater economy of movement and the relaxation phase of the 'double peak' pattern of muscle activity as described by McGill, Chaimberg, Frost, and Fenwick;[89] reinforced by the fact that the elite athletes achieved their highest hamstring activation faster than the novices during the pre-impact phase. Post-impact, there was greater activation of the vastus medialis and a later stimulation of the hamstrings, which may indicate a more effective follow-through and a faster recovery speed for a quicker follow-up.

The aforementioned mechanisms support how experts can better adapt their coordination than novices can. Adaptability is related to the suitable combination between the 'stability' and 'flexibility' of a behaviour that typifies expert performance.[2, 83] Among the key properties of complex and dynamical systems that correspond to adaptability are meta-stability, a state in which rich and varied movement patterns spontaneously emerge in performance, and 'variability', where these fluctuations are exploited to produce functional movement solutions.[2] Experts are thought to demonstrate greater movement variability during a task with more stable task outcomes.[83, 90] Movement variability is considered functional as it allows for more flexibility for movement adaptation and error correction during skill execution and learning progression.[83] This feature has been referred to as 'active functional variability' in a study of the throwing pattern of handball players of different skill levels.[91] Here, joint trajectories of novices were characterised by random variability, while experts increased active functional variability. The authors referred to this skill as 'deceptive motor expertise', which reflects the performer's ability to conceal the intent of their action through variable movement pattern to make it more difficult for the goalkeeper to anticipate.[91] Deception by movement variability can be applied to striking actions in combat sports, especially if combined with variability in preparatory movements. These combinations could also serve as an 'enquiry phase' where the performer explores the effectiveness of different actions to learn the strengths, weaknesses, and strategies of the opponent.[90] In contrast, variability also occurs randomly (called stochastic), in which each possible outcome is equally likely to happen.[92] To distinguish movement variability between participants of different levels of expertise, previous research has used cluster analysis,[91] standard deviation,[93, 94] variable error,[95] and the coefficient of variance.[96]

Coordination variability has been described to have a U-shaped curve when related to skill and consequent performance.[93] That is, less skilled performers displayed greater random variability, while those with intermediate skill had decreased variability, and highly skilled performers showed greater functional variability. The high variability among less skilled athletes signify an exploration for functional solutions. Intermediately skilled athletes may have stabilised their coordination thereby decreasing variability. Greater variability in highly skilled athletes suggest greater flexibility in adapting to changing performance conditions.[93] Additionally, the phases of an action appear to be a factor in the magnitude of variability. In studies on table tennis and golf techniques, variability has been found to decrease in several critical performance variables as the paddle or club approaches impact with the ball.[95, 97] Although this pattern, termed 'funnel-like' or 'zeroing-in', was not clearly demonstrated to be different between novices and experts, results suggest that the terminal phases of a kinematic sequence require greater stability.[95] No study was found on expertise-related differences in the variability of critical variables in striking actions in combat sports.

It is clear from the current knowledge that expert performance is kinetically distinct and is partially a result of kinematic and neuromuscular factors. Some appraisal of the design of the reviewed works was sporadically presented. Research on the differences of certain variables between participants with different expertise levels were reviewed, as well as issues around movement variability. The next section will further expand on these ideas.

2.3.2 Roundhouse Research Protocols

Much of the research on the taekwondo roundhouse kick used systematic designs[6] wherein variables were controlled and manipulated in order to better observe key factors of performance.[21, 22] Several studies examined participants while kicking without a target[22, 68, 74, 78], or a static or fixed target.[46, 71, 73, 77, 78, 98-100] While this approach increases measurement control, it also limits performer-environment interactions present in competition and training settings, and thus ignoring or underestimating the influence of the factors found in those settings.[6] Research designs that are representative of actual performance constraints can lead to more accurate appraisal of the critical aspects of the technique and allow for the development of training tasks to achieve the movement goals.[101] Another difference between research and practice is the common research procedure of participants kicking with the back leg,[62, 71] which is contrary to the front-leg kicking techniques that have become popular since the start of the use of PSS in competition.[102] However, some research observed the kick on a moving target and/or as part of a kicking combination. Chang, Chang, and Tang[103] examined the angular displacements of the lower segments and GRFs while participants performed a jumping double roundhouse kick. The study's design enhanced the representativeness of the task to actual performance environment by analysing the kick as part of a combination, a situation more commonly found in competition. Roosen and Pain[23, 24] observed peak foot velocity and joint angle changes during a combination of three alternating roundhouse kicks performed at 'normal' (i.e., training maximum) and '100%' (i.e., competition maximum) modes while kicking an opponent holding pads and moving in coordination. This study was a positive step towards providing task-specific information about the dynamical interaction between taekwondo athletes and their environment, which points towards more representative research design and training methodologies.

Common targets used in research are punching bags, kicking dummies, shields and focus mitts, pads or paddles. A few investigations that described or illustrated the exact use of the pads indicated tilting them downward "for a comfortable contact between the kicking instep and target"[71] (p.100).[23, 77, 88] Kicking an angled target may produce distinct kinematic and kinetic outcomes from kicking a target with perpendicular surfaces, such as a torso or a head. Only one study was found that used live armoured targets. Kim et al.[104] analysed the co-activation index (CI) between agonist and antagonist muscles in differently skilled taekwondo athletes while kicking a live target. There were two experimental conditions: during the static target condition (ST), the target was in a sparring posture without any additional movement; in the erratic-dynamic target condition (EDT), the target was asked to perform *ditgi* (a bouncing movement that involved random feinting moves). Elite athletes recorded higher CIs in the hip and knee joints than sub-elite athletes, and the difference was more pronounced in the EDT condition. One of the implications of the study is that the movement coordination pattern for a representative target is distinct from that of a static one, which has clear implications for practice and research. Therefore, while kicking without a target and kicking a static target may have their value in the progressive learning of the skill, it could be argued that these are less representative of actual training and competition environments and may reflect different performance results.

Scoring points determines the outcome of taekwondo competitions and most research suggests that the impact force and execution time of techniques are important factors.[21, 62, 75, 81, 82] While there is no consensus on the unit of measurement of impact force of kicks, the common way of determining it is by instrumenting a heavy target (a punching bag or a kicking dummy) with sensors for participants to strike. This method is appropriate to standardise testing conditions but is a long way from exemplifying training and competition environments. In recent years, results in competition have been determined with the use of the PSS and its precursor, the EBP.

A working prototype of the EBP was first described by Chi, Song, and Corbin in 2004. The investigators tested how suitable the sensor was in measuring the amount of force imparted by different techniques. Because of the few participants, the investigators were challenged on how to determine the threshold for a valid 'powerful' technique. There was an argument between an absolute threshold that every technique must meet, and a relative threshold that varies according to experience. Their recommendation leaned towards the latter, with eight watts as the power threshold for advanced players (red and black belts), and four watts for intermediate competitors (green to blue belts). Their prototype system allowed the adjustment of the scoring threshold.[105] The change to electronic scoring technology has seen changes in the techniques used in competition. Front-leg roundhouse kicks were previously favoured because of their speed, were initially too weak to register points on the EBP.[18, 19] However, as the impact threshold for a point on the EBP continued to be adjusted over the years, front-leg kicks are once again a preferred attacking technique.[102] In spite of poor validity and inter-trial reliability in the past,[106] the EBP (now renamed the PSS) is now the definitive method of determining the "*validity* of the technique, level of impact, and/or valid contact to the scoring area".[69] In fact, the reliance on the technology is so absolute that points that are scored (or not scored) on the PSS shall not be subject to Instant Video Replay, wherein an objection to a judgement by the officials can be settled by an immediate review of the video replay.[69] Therefore, using the PSS to register kicking effectiveness in research designs represents the tournament environment most accurately. However, no research on technical and tactical effectiveness on the PSS has been found.

In summary, much research has been conducted on various aspects of the taekwondo roundhouse kick. Observations were simplified by dividing the kick into phases, although there is no consensus on the division of these phases. The ranges of motion of the joints thought to affect the kick's performance have also been examined, as have the velocities of these joints and total movement time have been monitored. Kicking coordination has been quantified via phase relationships and pattern change. Research has also measured the stability of the supporting foot. As far as can be determined, these variables were selected by researchers rather than coaches, uncovering what could be a disconnect between research and practice. Some of these factors have been previously compared between participants of different expertise levels in order to clarify expert performance of the technique. These measures provided guidance in analysing the coaches' data and in translating these to observable variables for the following study. Additionally, some research was reviewed on the influence of skill on kicking performance and the kinematic and neuromuscular variables affecting it. The review also showed that most work done is based on a systematic, rather than representative research design, which further justifies the current research's novel research strategy.

2.4 Ecological Dynamics

Ecological dynamics is an approach to studying human behaviour that integrates the concepts of dynamical systems theory and ecological psychology.[107] In this approach, performer-environment interactions are considered when observing the emergence of patterns of coordination in skilled sports performance.[13, 108] Dynamical systems theory views the performer as a complex system composed of many interacting parts and motor system degrees of freedom, forming patterns of coordination shaped by shifting constraints during skill acquisition.[43, 107] These constraints provide the boundaries in which functional behaviour emerges and self-organises.[3, 90] The influence of interactions between the performer and environment on human behaviour is emphasised in ecological psychology.[6, 7] In this method, information is perceived by the performer and is exploited to support the regulation the consequent actions.[7, 107] The following review presents relevant research on the foundations of ecological dynamics, and then focusing on the manipulation of constraints for skill acquisition. Research on representative learning design, an integration of Gibson's work on ecological psychology[7] and Brunswik's representative research design,[6] will follow. Lastly, literature on learning design in combat sports is presented.

2.4.1 Ecological Psychology and Dynamical Systems Theory

Ecological dynamics is an approach to studying human behaviour that integrates the concepts of dynamical systems theory and ecological psychology.[107] Ecological dynamics supports the importance of performer-environment interactions in skill acquisition.[1] The performer learns a skill by perceiving key information from their environment and then scaling their movement coordination according to their body and action competencies.[109] As learning proceeds, performers generate changes in the environment, e.g., fluctuations in inter-individual interactions, that provide further cues for learning progression.[110] Skilled performers are able to achieve consistent performance in the changing environments of competitive sport, an ability termed 'dexterity'.[43] Ecological dynamics attempts to describe how performers learn to exploit available sources of information to control performance, and which perceptual cues aid learning.[1] The rest of this section discusses the theoretical foundations of ecological dynamics, and the next section focuses on the features of the performer-environment system.

Ecological psychology strives to understand behaviour in the context of the performer's interaction with their environment.[6, 7] The performer-environment relationship is mediated by the performer's direct perception of the 'values' and 'meanings' of things in the environment.[7] The accurate and efficient coupling between perception and action produces functional movement solutions.[5, 7] The cues picked up from perception are termed affordances, or opportunities, that regulate action.[7, 111] In combat sports that involve striking techniques, one significant factor that creates affordances is the interpersonal distance (IPD) of the fighter-fighter dyad.[90, 108, 112] The IPD regulates the actions and intentions of the performer as it relates to the perception of target 'strikability'.[12, 112] During a fight, fluctuations in IPD are contingent on the defensive/offensive interactions of the fighters. Perception of the most useful variables within these interactions can be developed with practice, and has been termed education of attention.[7, 110] For instance, expert karate fighters displayed faster and accurate decisions in different fight scenarios than novices, which could be attributed to their greater perceptual and cognitive skills.[113] That study also demonstrated that experts produced more refined karate-specific movement solutions compared with the novices.[113] It highlights the other component of the perception-action coupling; that the performer needs technical skill and the knowledge of its applicability in addition to aptitude in perception. Hristovski et al.[112] showed how boxers selected the most efficient punches that are appropriate for a given IPD. Learning a variety of techniques will increase a performer's strike options for a variety of circumstances. From a theoretical point of view, this supports the need for practice contexts that are of comprised of relevant affordances that will aid in the performer's education of attention while learning appropriate skills.

Within the dynamical systems theory, the complex systems that make up human behaviour are seen to be constantly changing over different timescales.[114] Coordinated behaviour emerges in dynamic contexts as a result of the performer's intentions and self-organises within the restrictions of the constraints of that action.[114, 115] This is achieved because human movement systems have the attribute of degeneracy, in which structurally different components of the biological systems are able to self-organise to achieve similar task outcomes.[2, 12, 90] With increasing levels of expertise, performers are able to focus on the key information sources in a variety of performance contexts to exploit system degeneracy.[2] For instance, in a study of elite fencers, the opponent's approach velocity influenced the perceiver's perception of affordances more than the opponent's stature.[111]

The coordination of behaviour may fluctuate in a non-linear manner because of changes in factors acting on the system.[13, 112] These factors are referred to as control parameters, and they guide coordination through different states of organisation even though they do not contain specific information about the organisation of the system. The different organisational states of behaviour are termed order parameters and these are the variables that contain the collective information of each organisational state.[112, 116] For example, in boxing, the direction of fist-target impact is most likely the order parameter that determines the path of different punches; whereas, the control parameter in attacking and defending in boxing is thought to be the scaled distance to a target (i.e., IPD).[12, 45] Therefore, in striking combat sports, IPD can both constrain and guide behavioural patterns.[108] Skilled fighters are more attuned to the changes in IPD during a fight and quickly exploit system degeneracy to adjust striking techniques to score points.[90] Enriching practice environments by manipulating constraints will enhance performer attunement to information sources to produce functional movement solutions.

2.4.2 Constraints

Constraints are factors that influence performance within the learning environment. They consist of the following: Organismic constraints are the unique characteristics of individual learners, which include physical, psychological, and emotional features. Environmental constraints refer to the qualities of the learning context, which include its physical attributes (e.g., light, temperature, noise, etc.). Task constraints are more specific to particular performance settings and incorporate the rules, equipment, boundary markings, and, most importantly, the sources of information available to the athletes for them to regulate their actions (i.e., other team members, opponents, etc.).[3, 117] Socio-cultural factors, such as expectations and social customs, have also been considered environmental constraints.[13] For instance, Maloney, Renshaw, Headrick, Martin, and Farrow[118] showed that taekwondo fighters were less aggressive and more predictable in training with their teammates than they were in competition with unknown opponents. Task constraints can also include instructions by the coach in practice sessions.[116] Roosen[119] demonstrated differences in kicking coordination from different instructions (i.e., regular or 100% modes). Coaches with knowledge on the different constraints can maximise the learner's search for effective movement solutions by providing instructions focusing on these variables, as well as facilitating practice conditions for these changes to occur.

The constraints-based approach to learning identifies the type of interacting constraints that affect skill acquisition in learners.[3, 4] Based on Gibson's[7] work, learners are thought to be surrounded by information sources (e.g., visual, acoustic, proprioceptive) that support decision-making, planning, and movement organisation during specific performance contexts. The athlete can use this information as affordances for action. The ensuing movement then generates new information that will support further action, leading to a recurring relationship between perception and movement. Natural pattern-forming predispositions can develop as system components (e.g., muscles, joints, limbs, segments), spontaneously adjusting to each other as learning takes place. The system components are open to the influence of constraints and display propensities towards stability and instability based on the stage of learning.[3] There is also a potential for non-linear behaviour characterised by small skips, jumps, and regressions in learning.[4] Complex systems tend to self-organise into stable patterns of behaviour as learning occurs.[120] Early in learning, novices at the 'coordination' stage will naturally assemble a functional coordination pattern to achieve the skill at a basic level. As the constraints change, the learners will move from a stable to an unstable pattern until they once again self-organise their system components into another stable state, which would be a more advanced version of the technique. When the performer can successfully adapt to the changing constraints, they are said to be at the 'control' stage of learning. Finally, experts at the 'skill' stage of learning can quickly vary the skill's degrees of freedom to be energy-efficient or creative to fit the situations in the actual performance context.[3, 4, 121] Bernstein[43] referred to this concept of achieving the desired outcome through numerous movement pathways as motor equivalence.

Identifying constraints to induce appropriate perception-action couplings is challenging for coaches, however, attempts have been made by integrating experiential knowledge with statistical analysis of competition results. For instance, McCosker et al.[122] started with candidate variables from the knowledge of elite long jump coaches, then statistically examined the effects of each variable on jump performance of athletes over 17 years of competition. Key constraints were related to the individual (e.g. the intended performance goal), the performance environment (e.g. strength and direction of wind), and tasks (e.g. the rule for the front foot behind the foul line at take-off).[122] Studies have also shown how some constraints shaped reorganisation in sports techniques. Barris et al.,[9] for example, revealed that competition divers were able to adapt their approach and hurdle phases and stabilise performance outcomes despite the task constraint of not allowing divers to balk (i.e., noncompletion of a dive attempt). Hristovski[45] also found that instructions as a task constraint produced more punching solutions by a novice boxing learner. Conversely, Chow et al.[115] demonstrated changes in kicking coordination as soccer players practiced to kick a ball over a barrier without any additional feedback. A similar response was found in novice taekwondo participants who learned the roundhouse kick without augmented feedback.[46] Viewing performance holistically, Maloney et al.[118] indicated that socio-cultural constraints produce different affective and behavioural responses between training and competition contexts. Physiological responses were also found to be different between practice and competition environments,[123] suggesting that constraints affect performers in different ways. Based on the evidence, preserving the performer-environment interactions by manipulating constraints in representative learning contexts can facilitate the emergence of functional movement solutions by allowing the performer to attune to important affordances.

2.4.4 Representative Learning Design

Pinder et al.[5] based their representative learning design (RLD) framework on Brunswik's representative research design.[6] The term 'represent' was originally defined as the organisation of constraints in an experimental design to embody the behavioural setting to which the results are meant to apply.[5, 6] The process requires sampling constraints from specific performance environments that preserve perceptual cues in order to regulate the performer's actions.[6] For example, the presence of an opponent while learning a sports skill has been shown to affect movement coordination.[94, 124] In combat sports, performers use information from the opponent's movements to predict their intended actions before they initiate their own movement. Skilled performers may even manipulate their opponents by drawing out the initial movements. This example exemplifies another foundation of RLD, Gibson's insights on perception-action coupling.[7] Skilled performers depend on the accurate and efficient relationship between perceptual and motor skills, focusing on the relevant environmental cues and producing the appropriate movement solutions.[5] Therefore, preserving these couplings in learning environments may produce better skill transfer to competition contexts.

Pinder et al.[5] provided principles in creating an RLD. Coaches should create appropriate dynamic, rather than static, practice tasks that sample information sources from performance contexts. For instance, Hristovski[45] described a learning design for a novice boxer that allowed the learner to generate a variety of punching solutions on a moveable punching dummy, then on boxing mitts, and later, during sparring. In RLD, learners should also be able to closely connect the indicators of success between the learning context and the performance environment.[5] In taekwondo, sparring in practice using the PSS will directly signify success in both contexts. Additionally, dyad training is beneficial as it increases the learner's motivation by adding the element of competition.[125] Attentional load for both learners in the dyad is also high facilitating more focus on the task.[126] Oh[127] outline steps in instructing and assessing taekwondo that culminates in non-contact sparring. However, Maloney et al.[118] have demonstrated the disconnect between sparring in practice and fighting in an authentic competitive setting. But both practice sparring and competitive fighting must be implemented sparingly to help prevent injuries and burnout, therefore requiring other forms of dynamic practice tasks.

Preserving information-action couplings in practice leads to skilled performance as learners become more attuned to the key information cues in their environment and respond with appropriately functional actions.[5, 107] Mann, Abernethy, and Farrow[128] demonstrated this aptitude where skilled cricket batsmen anticipated the direction of balls bowled towards them better than novices. Only the skilled athletes improved their prediction as the response condition became more representative (i.e., from verbal stimulus only to full-body movement with bat). Similar differences in ability were found in a karate defensive response between experts and novices.[129] The participants' reaction times and decision-making ability to two types of video stimulus presentation (simple and realistic) were measured, and the experts showed greater anticipation and better decisions in the realistic condition. The experts performed similarly as the novices in the simple condition implying that expertise did not affect anticipation to non-karate specific stimuli. The representativeness of the attacking stimulus was improved in another karate study wherein dyads were observed by three-dimensional motion capture.[130] The attacker randomly executed three techniques to the defender, and results showed that the technique type and IPD correlated strongly with reaction times. Surprisingly, the front-arm punch was easier to anticipate than the other rear-arm and rear-leg techniques and may have been due to the detection of prior distance adjustment before its execution. However, the participants were less likely to identify the techniques that came from the rear and be able to appropriately defend against them. It was not clear if the attackers were instructed to intentionally score on the defenders. Nevertheless, these studies emphasise the importance of context-specific information-action couplings in representative tasks.

Another quality of expert performance is its adaptability to changing constraints. Adaptability is the suitable balance between the stability and flexibility of movement coordination and is characterised by movement variability.[2] As examples, Estevan et al.[81] and Falco et al.[21] compared the execution time and impact forces of taekwondo roundhouse kicks at three different distances (short, medium, and long) between medallist and non-medallist fighters. Medallists elicited greater impact force at the short and long distances than did the non-medallists, indicating the stability of the kicking coordination while execution technique was adapted to the changing distance constraint. This functional variability allows expert performers to exploit internal and external perturbations within the system to produce a stable movement outcome.[114] In the case of the taekwondo roundhouse, skilled athletes seem to adapt their coordination to different distances mostly by modifying their pivot hip displacement.[71] Therefore, in RLD, constraints can be manipulated in order for individual learners to be able to search for a functional 'emergent' action based on the current context. Practice tasks should be varied enough to mimic the dynamic nature of performance environments in order for the learner to be adaptive in hunting for appropriate movement solutions, what Bernstein[43] termed 'repetition without repetition'. However, the functional pattern of a particular skill should be consistent over time, resist perturbation, and be reproducible in different situations. At the same time, the performer should be able to adapt the technique to find a solution based on the context at hand.[131]

Movement variability in skilled performance also indicates the exploitation of degeneracy by having multiple solutions to a movement problem.[13, 90] In other words, learning can be described as a progression towards stable outcomes with increasing performance-related variability.[83] Carson et al.[83] also noted that the nature of the co-variability of between variables in the system is more important than the direction of change within each variable, and that this process stabilises and re-stabilises with changing constraints. For example, semi-professional Rugby Union players displayed greater movement variability with stable outcomes while punt kicking than less skilled players.[132] The preceding study exemplifies movement variability in which the control of a given technique is adapted. However, in combat sports, performers can also use adjust global behavioural variability by changing the coordination solutions based on the affordances present.[90] Hristovski et al.[112] and Maloney[13] demonstrated this ability in punching and kicking techniques, respectively. Both studies showed how the fighters adapted by changing their striking techniques to different distance constraints as they tried to impart sufficient force onto the target (e.g., from a jab to a hook punch as the distance reduced). These arguments emphasise the importance of measuring movement variability in skill acquisition and learning research.

2.4.5 Learning in Combat Sports

Combat sports inevitably have most of their foundations in traditional martial arts. The goal of traditional martial arts is to master oneself by training the body and mind by way of meditation, forms, prearranged and free sparring, and breaking.[133] Forms (*hyung* in Korean and *kata* in Japanese) are choreographed sequences of defensive and offensive techniques against imaginary opponents. These are an important component of traditional training that serves to develop harmony of body and mind. Constant repetition of forms supports basic technique learning and helps develop control, confidence, balance, and coordination. When the performer has been judged skilled enough to advance, they then learn new forms to acquire new techniques.[133] This type of learning forms part of enrichment theories of learning, as exemplified by the Adaptive Control of Thought-Rational (ACT-R) model.[134] The ACT-R model suggests that human behaviour is predicted by a fixed set of mechanisms that use procedural (how to do a task) and declarative (facts about the world) knowledge.[134] Applying this model to learning martial arts techniques, procedural knowledge usually comes from an expert model that the learner strives to master by consistent (or invariable) repetition. In forms training, declarative knowledge (e.g., distance and dimensions of opponents) is usually imagined as the patterns are usually performed alone and with no targets to strike. Therefore, forms training constitutes abstract templates for movement that have little connection to a representative combat environment. While consistency in forms may be an end in itself, as in competing in forms competitions or performing in a grading test, the ecological dynamics approach may be more useful in sparring contexts. However, representative practice tasks seem to be unpopular among practitioners. Gomes, Morato, Terisse, and Almeida[135] interviewed physical education teachers and martial arts masters and discovered that while there was agreement on the importance of tactical training, technical instruction still predominated upon deeper questioning. Most of the respondents did not believe that playful tasks are part of a serious class regardless of the age and development of the students.

This traditional approach may be briefly useful for novices in the coordination stage of learning but, as movement patterns become more stable, a more representative approach might better prepare the learner to adapt to changing information-movement couplings in sparring.[1] However, there is minimal research that investigates the applicability of this process to effective learning in combative sports. The following works will be limited to those concerning teaching and learning in combative sports in general, and then instances on specific styles.

While the grading test skill requirements in taekwondo are set by the Kukkiwon (World Taekwondo Headquarters), the curriculum to teach these skills are not. To address the gap, Oh[127] proposed teaching and assessment methodologies specific to taekwondo in 'authentic settings.' A format of instruction with several steps was proposed that progresses from technique practice without a target to striking different implements while the partner randomly presents the target at different levels and orientation while commanding specific techniques. The speed and variety of techniques may be progressed according to the learner's stage of development. The learner's decision-making skills will be challenged further in the next step, where the instructor presents unexpected targets without specifying the techniques to be delivered; learners decide on their own which is the most appropriate technique for each scoring opportunity. The task becomes even more representative in the next step in which time (30 seconds) and space (the official contest area) constraints are imposed. The same constraints are exploited in last step, but this time learners actually engage in non-contact sparring. While the injury risk is lower in this type of task, the progression up to this point may be flawed as the movement coordination from full contact (i.e., with a target) to non-contact may is different in the in-phase movement of the hip and knee.[76] Instead, the task may be simplified by limiting either the techniques to be used and/or the target area (e.g., no head kicks) but allowing contact to armoured partners. Formative feedback may take the form of coaches' comments, but learners can also get instant feedback from the task outcome. A traditional gauge of scoring success is the audible pop on the target upon impact[18] and may be easily used in a class setting. Summative assessment (i.e., the number of audible pops on the target) may be completed at the end of each session/unit within an authentic competitive setting.

Examples of representative practice tasks learning martial arts are presented below. Gomes et al.[44] instructed a judo throwing technique (*o-soto-gari*) to children in two practice contexts: The motion group performed the throw dynamically with actual projection (i.e., throwing) of the opponent, while the static group executed the technique with no preparatory motion and no projection. Judo experts determined that after the training period, the motion group produced superior transfer and retention. These results show that even at an early stage of learning, simplified representative tasks benefit skill acquisition. Introducing tactical games early may also make practices more fun and less tedious for children, particularly during the acquisition phase of learning. A follow-up study that investigated the differences between whole-part practice of the same technique reinforced their previous findings. Gomes et al.[11] divided children into four practice groups: (1) static traditional practice, (2) dynamic traditional practice, (3) whole practice with preparatory movement (i.e., a feint), and (4) progressive introduction of parts with preparatory movement. While all groups improved the global technique, the latter two groups improved performance of the feint that unbalanced the opponent and made the o-soto-gari more effective in competition settings. The dynamic practice trials allowed the learners to time the execution of the technique's components appropriately to the affordances presented by their opponent leading to improved success in the task. The *o-soto-gari* was selected as it is performed close to the ground and is relatively simple. As such, it offers less risk to children, implying that whole practice tasks may be indicated when safety concerns are considered in addition to the technique's complexity.

Whole practice tasks for complex techniques will be more functional with the presence of specifying information from performance contexts.

Only two studies on learning striking techniques in combat sports was found. Hristovski[45] studied the effects of a constraints-based training programme in a case study of a novice learning the rudiments of boxing. In contrast to many boxing trainers who use a static punching bag, the trainer used a moveable punching dummy, which he moved in different directions to generate variability in the learner's movements. Instructions were given on maintaining the best fighting distance from the target and to constrain the target areas to be. The training technique produced many new punching combinations that were not present when the learner worked on a predictable punching bag. The trainer used the same method with punching mitts, increasing the frequency of directional changes over time as the learner became more proficient at adapting to affordances. Eventually, the mitt work was substituted with situational sparring with more advanced boxers, with additional instructions of creating high frequency combinations on target areas Although the task outcomes were not measured, representative practice tasks may increase positive training transfer to enhance skill acquisition and retention in boxing. A similar strategy of offering dynamic targets may be applied to taekwondo kicking techniques. Coupled target movement can help adaptation through both movement and behavioural variability.[90]

A study on taekwondo technique learning did not use augmented information on learners. Kim[46] found changes in segmental velocity and kicking leg pattern in novice participants learning the roundhouse kick after a five-week practice period. The participants were required to perform the kick with maximum velocity and accuracy against a target. The only instruction provided was to set the kicking foot back in the initial ready stance and hit the target with the instep. No augmented feedback was given other than when they did not strike the target with their instep. However, the participants were given foot velocity and accuracy data from the former session before each subsequent session. In effect, the participants were allowed to self-organise their systems to find the appropriate solution to the task constraints.[3] Not only did they increase their foot velocity, their accuracy improved over time, indicating that the learners may have already established a basic kicking pattern prior to practice that allowed them to improve performance. This study exemplifies the 'hands-off' approach to coaching wherein the coach allows the athlete to adapt by themselves within a well-designed learning environment.[136] From these encouraging results, opportunities are open to study the effects of constraints-driven methods on coordination patterns and performance outcomes of taekwondo techniques, especially those used in dynamic competitive contexts.

To summarise this section, only a small number of studies have been published on the effects of non-traditional learning methods on combat sports and martial arts. Some of the studies proposed strategies that involved tactical games and teaching in authentic settings for skill acquisition, but only a few attempts have been made to validate these suggestions. Research on judo, boxing, and taekwondo reinforce the value of teaching strategies that complement the traditional model by exploiting constraints to make the practice tasks more representative. Using expert knowledge to help choose the appropriate techniques and constraints appears to be an important way to successfully apply this approach to the different stages of skill acquisition. Furthermore, applying a model of the coaching-biomechanics interface can help identify key critical variables that can be improved by a representative learning design. The verification of critical factors of sport skills using representative methods can further focus on the most important variables for observation. In investigating a taekwondo skill, this research seeks to uncover broader implications for coach-researcher collaborations to identify critical variables and how those variables can be taught.

CHAPTER 3

EXPERIENTIAL KNOWLEDGE OF EXPERT COACHES ON THE CRITICAL PERFORMANCE FACTORS OF THE TAEKWONDO ROUNDHOUSE KICK

This chapter comprises the following manuscript:
Bercades, L. T., Oldham, A., Lorimer, A., Lenetsky, S., Millar, S.-K., & Sheerin, K. (2022). *Experiential knowledge of expert coaches on the critical performance factors of the taekwondo roundhouse kick*. Published in the International Journal of Sports Science & Coaching on 27 December 2022.

3.1 Preface

Chapter 2 established the importance of expert knowledge to identify variables important to coaches and the need for a common language shared with researchers. Chapter 3 presents and analyses the knowledge of expert coaches specific to the critical variables of the taekwondo roundhouse kick. The coaches' knowledge was translated to biomechanical variables in order to demonstrate the coaching-biomechanics interface as a useful way to discover knowledge.

3.2 Introduction

Coaches' expertise is argued to be based on declarative[28] and contextual[137] knowledge regarding their sports. Such knowledge might include how scientific principles apply to sport as well as "look and feel" of skilled performance.[65, 31] This knowledge is also shaped by the pressure of competition, ensuring that only the most effective concepts survive, therefore it is argued to be of high value.[138] While this knowledge may lack the formality or vocabulary of sport science, it nonetheless contributes to understanding and stimulates research.[64] Consequently, expert coaches' experiential knowledge can provide significant insight for researchers and sport science practitioners about elite performance, provided that it can be captured in a valid way.

Early work by Côté et al.[139] analysed coaches' knowledge to develop a coaching model identifying the different components that could affect high-performance coaches in their work. The central components are competition, training, and organisation, and are defined as the coaching process.[139] Subsequent research on expert gymnastics,[58] sprint,[32] and golf[61] coaches provided general terminology to describe fundamental actions within their respective sports. Critical factors have been defined as important aspects of performance that are related to the efficiency and effectiveness movements.[27] Expert coaches and athletes identified the critical factors of skills such as the volleyball spike,[28] sprint running,[29] rowing,[31] golf,[33] and the run-up task in track and field, gymnastics, and cricket.[63] Noteworthy are the factors uncovered by researchers that experts find difficult to describe[9] and those that were not supported by the research at the time.[29, 32, 33]

Capturing expert coaches' experiential knowledge may improve the relationship between practitioners and researchers since there may be a gap, as Williams and Kendall[59] claim. In responding to how research questions "are determined," the researchers ranked "the scientist alone raises the question" first, while the coaches ranked “together the coach and the researcher should determine the question” first.[59] This disparity was also highlighted by Waters et al.,[60] who compared the experiential knowledge of coaches and biomechanists on elite sprint running technique. The term “coaching-biomechanics interface” has been used to describe the cooperation between coaches and biomechanists.[35, 37] The coaching-biomechanics interface starts with coaches’ knowledge gleaned from interviews or observations, which is then combined with scientific concepts, to help explain sports technique.[35] While some research was found on the experiential knowledge of expert coaches and athletes reinforcing theoretical knowledge,[30, 31, 63, 64] only a few were found where coaches’ knowledge was used to guide ensuing research.[35, 36] Obtaining knowledge where research-driven practitioners and coaches agree should create a conduit for the exchange of ideas, helping both. Some consideration needs also to be given to how data is collected. It is common to have coaches recall elements of their expertise rather than exercise it in a representative context. This it may be argued is not ideal, data may be enriched where coaches are able to view actual performers in context and asked to make coaching related decisions.

Taekwondo is a traditional Korean martial art that emphasises striking with the hands and feet which has gained popularity as a combat sport because due to inclusion in Olympic Games.[16, 17] Unlike many competitive combat sports, fighters accumulate points by striking their opponent’s torso, which is covered with an instrumented body armour known as the Protector and Scoring System (PSS). The PSS armours have sensors in limited areas as denoted by silver dots, requiring high accuracy to hit them (Figure 3.1). Competition rules are continuously revised in response to external feedback, judging transparency and safety concerns necessitating frequent adjustments of techniques and tactics.[18, 19, 102, 140] Identifying the critical factors of scoring techniques is a necessary ongoing task in instruction and coaching, especially when adapting to frequent rule changes.

Figure 3.1: ***Daedo TK-Strike Protection and Scoring System Body Armour***

The taekwondo roundhouse is the most used kick in competition[87] and has been widely studied (e.g., Falco et al.;[21] Ha & Kim[22]). To date, most variables of interest, such as joint angle range of motion,[22] centre of mass movement,[75] and intra-limb coordination,[76] have been determined by researchers seemingly without the insight of expert practitioners. Estevan et al.[34] collected data on the key variables of the taekwondo roundhouse kick perceived by coaches to develop a self-efficacy scale for the taekwondo roundhouse. A panel of experts was interviewed to determine specific examples of mechanical and technical factors pertinent to the roundhouse kick. After pilot testing, the original 25 items were reduced to 12 items: seven on execution technique, three that complement previous items and two generic items on taekwondo kicks.[34] While some terminology used in the technical items may be observed biomechanically, for example, "Kicking from execution distance with sufficient impact force", some may need further clarification for future testing, such as "Executing the technique with the correct body allocation".[34] Translating expert taekwondo kicking knowledge to biomechanical variables seems to be a logical step to greater practitioner-researcher cooperation to best benefit performance. Adding the detailed perspective of coaches which is lacking in much current biomechanical research will guide future investigations that focus on producing meaningful knowledge for all stakeholders.

The primary aim of this study was to capture expert taekwondo coaches' experiential knowledge of the critical factors of the roundhouse kick in a representative manner. The secondary aim was to evoke the coaching-biomechanics interface and translate the coaches' knowledge into observable biomechanical variables for future investigation. The final aim was to elicit further expert knowledge to assess the usefulness of the resulting variables. From an epistemological perspective, coach knowledge is subjective, situated in a triad made up of the coach, the athlete, and the performance context. In contrast, sport science generates knowledge that is unique to research settings and is at best generally applicable in certain circumstances, often limited by research measurement tools. The present study sought to formalise and examine the effectiveness of this relationship. In so doing, our overall goal was to present a practical process which encourages practitioner-researcher collaboration by integrating expert and theoretical knowledge.

3.3 Methods

The study followed three phases as follows: Phase 1 was the initial compilation and analysis of expert knowledge from coaches. This expert knowledge was then translated into observable, measurable, and coachable variables by the authors (LB, TO and AL). Phase 3 involved another set of coaches (referred to as assessors) that assessed the understandability and coachability of the Phase 2 variables. Institutional ethics approval was obtained, and all participants gave informed consent (AUTEC #15/169).

3.3.1 Study positioning

The researchers held a relativist ontology (i.e., social reality constructed by humans and one that is fluid and multi-layered) and a subjectivist, transactional and constructionist epistemology (i.e., the interaction of the researcher and the researched produce the 'findings') to focus on the coaches' subjective perspectives on kicking performance in the competition context.[141] Additionally, this paradigm acknowledges the intrinsic biases that researchers bring the analysis of the data. This position informed the use semi-structured interviews to understand the coaches' point of view, as well as the role of coaches in determining the value of derived items and themes.

3.3.2 Participants

Six taekwondo coaches participated in this study (see Table 1). Purposeful sampling[142] was undertaken using selection criteria from previously published methods.[143] Coaches: (1) had coached at club level for at least 10 years; (2) were currently coaching a club or team; (3) had developed at least one fighter who has taken part in major international competitions; and (4) had been recommended by a national and/or regional governing body as a knowledgeable and respected coach. Four coaches were interviewed in Phase 1, and two coaches (Coaches A and B in Table 3.1) assessed the data in Phase 3.

Table 3.1: ***Participants' Profiles***

Coach	1	2	3	4	A	B
Coaching experience (yrs.)	14	18	24	20	15	17
Country	New Zealand	New Zealand	Philippines	Australia	Philippines	Philippines

3.3.3 Procedures

Phase 1

A phenomenological approach was used in the study, wherein the coaches completed two tasks; they initially participated in semi-structured interviews where they were asked questions about critical factors[27] relating to the roundhouse kick as used in competition. The combination is typically composed of (a) a preparatory action, which is a hopping front-leg *cut-kick* (also known as a cut);[144] (b) a quick *transition*; followed up with (c) a *roundhouse kick* with the same leg (see Figure 2). This combination was chosen after consultation with a New Zealand national coach and two-time Olympian (L. Campbell, personal communication, January 12, 2015). Subsequent consensus from the interviewed coaches verified the relevance of this combination to competition. Guide questions for the semi-structured interviews were developed based on similar research.[31, 36] Questions incorporated the common components of the cut-roundhouse kicking combination relative to the skill level of athletes, as well as differences in skill levels (See Appendix A for guide questions).

(a) (b) (c)

Figure 3.2: Cut-roundhouse combination analysed by the coaches depicting (a) cutting kick [involves hopping forward with the supporting leg while carrying out a push-like kick with simultaneous hip and knee extension]; (b) transition; (c) roundhouse kick [characterized as a throw-like movement defined by hip flexion followed by knee extension].

The second task attempted to create representative conditions that are in closer agreement with the behavioural situation to which the results are intended to apply,[145] that is, the typical activity of critical verbal reflection by the coach during observation of an athlete's technique. Eleven advanced and eight novice taekwondo athletes were filmed to create short video clips that were shown to the coaches. Each coach was then presented with video clips depicting taekwondo fighters of varying skill levels in a random order, with the aim of helping them describe the critical factors in a representative manner. Presenting the coaches videos of differently skilled athletes allowed them to distinguish between skill levels, which was thought to be an essential part of this representative task in accordance with Dham et al.[146] The coaches' responses to the questions were recorded by video, allowing for comments, as well as physical gestures about critical factors, to be captured,[147] before being transcribed verbatim. Physical gestures were described alongside the transcribed comments they were referencing. The mean duration of the interviews was 57:49 minutes. This rigorous two-tier interview process can better distinguish between participant descriptions and opinions about observed phenomena,[148] and justifies fewer participants (between four and ten) in phenomenological studies compared to studies using grounded theory.[149]

Transcribed verbal reports were coded into blocks representing critical factors that arose from the interviews using inductive analysis[141, 150] via NVivo 11 Pro (QSR International, Melbourne, Australia). Critical factors were broken down into main themes and sub-themes that contained one specific idea, episode, or piece of information.[151] The first author [LB] and one other researcher with significant experience and knowledge in combat sports competition and coaching performed the inductive analysis. Each researcher reviewed and refined their respective themes by establishing coherent patterns in the data extracts, and, in the absence of such patterns, subsequently reworking the themes, or transferring the data into another theme.[152] Themes created independently by each researcher were then compared and debated to produce mutually approved, higher order themes.[153] A model of successful kicking was derived from these data using the hierarchical category system.[141] In addition to the two researchers, the second author [TO] reviewed the model for coherence, and discussions continued until the final model was agreed upon.[152]

Phase 2

The authors (LB, TO, and AL) discussed and determined a set of measurable biomechanical variables for future investigation. Discussions proceeded from main themes to sub-themes and decisions were based on the frequency of mentions of the coaches, relevant theory, and practical application in training.

Phase 3

The findings from the coaches and the resulting set of biomechanical variables were assessed on their understandability and coachability from two different expert coaches. This phase examined the trustworthiness of both the themes from Phase 1 and the translated variables in Phase 2. The two coaches were given a questionnaire asking about: (1) their coaching background; (2) the quality of each performance and the possible factors that differentiated them after viewing the same videos presented to the other coaches in Phase 1; (3) their understanding of the importance, and significance to the cut-roundhouse combination, of each biomechanical variable, after sample data from the previous coaches, and descriptions and illustrations of the proposed variables were presented. These coaches were also asked for their insight on the variable's coachability, how the variable differentiate skill level, and any changes they would make. For each variable, a 1-5 Likert scale was used to ascertain the assessors' understanding, level of importance, coachability, and how the variable differentiates skill level. Follow-up questions were used to solicit additional commentary with respect to changes coaches might propose for each variable.

The data collection process fulfilled criteria for methodological rigour set out by Guba and Lincoln.[154] The first criterion, credibility, was satisfied by asking the coaches to display their expertise regarding a phenomenon that is familiar to them in their day-today practice. To ensure this, coaches were not only asked for their opinions, but they were asked to view and analyse videos of different athletes performing the roundhouse combination. Transferability is the second criterion, and it was fulfilled by productive interactions with the data from Phase 1 and 2 by the researchers and coaches in Phase 3. As the data collection procedure was described in detail, the process achieved the next criterion, dependability. The last criterion is confirmability. Phase 3 satisfied this criterion in which different coaches were asked about the importance and coachability of the derived variables from Phases 1 and 2, thus confirming that the data are relatively free of bias. On the basis of these criteria, the data could "stand for itself" and the process of their collection could be judged by readers and other researchers, rather than sample sufficiency or data saturation.[155-157]

3.4 Results

The three phases of data collection, analysis, translation, and assessment, the critical factors of the roundhouse kick derived from the expert coaches, and the resulting key biomechanical variables are presented in Figure 3.3. The results are presented starting with the themes and sub-themes derived from the coaches in Phase 1, followed by the five resultant biomechanical variables in Phase 2, and expert assessment in Phase 3.

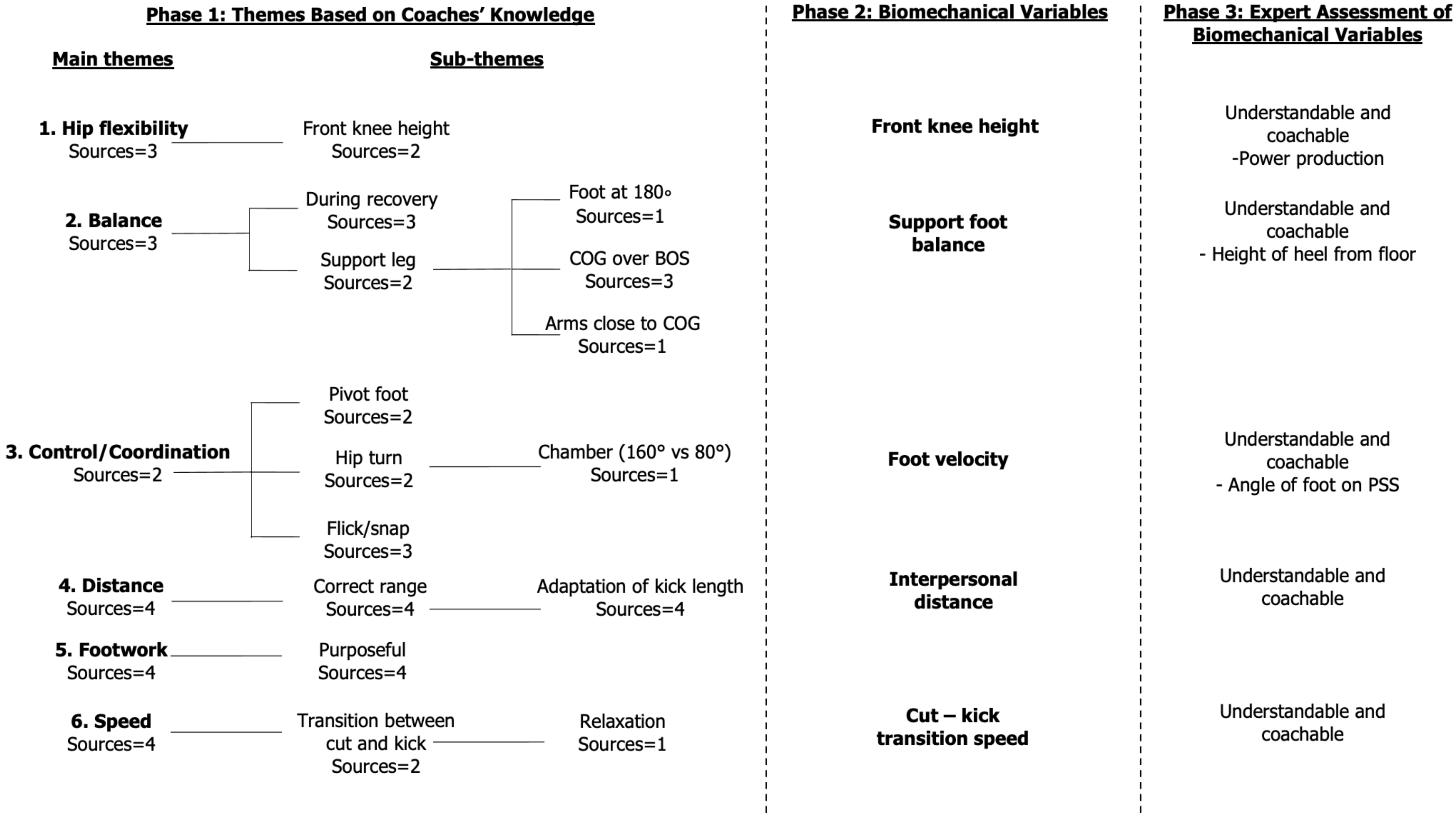


Figure 3.3: ***Summary of Findings of the Three Phases***

3.4.1 Hip Flexibility

According to the coaches, the main theme of hip flexibility is associated with the height of the front knee during the cutting portion of the kicking combination. The coaches indicated the need for a high knee during the cut for protection against attack and for greater flexibility in attack selection. As Coach 2 indicated: *"If the knee is high, he can still kick as he's lowering it. If the cut is lower, it's harder to raise the leg for a kick. But if the cut is higher, you can do either a low or a high kick.*" In Phase 2, front knee height was interpreted as the absolute angle between the supporting hip and the kicking knee with respect to the horizontal, taken at the highest point of hip flexion during the cut and during the kick (see Figure 4). Previous research has not examined this variable, however its impact on the performance was of high value to the coaches.

Assessors in Phase 3 reiterated the initial coaches' assertion that a higher knee offers more attacking options and added that it would also contribute to power production due to a more pronounced chamber (i.e., knee flexion prior to the extension). Coach A praised the 3D representation of knee height (*"It's a good visualisation of the high knee."*) and asked if they could use it to show to their students. Furthermore, they pointed out that it was easy to coach as the mid-level roundhouse is a basic technique and can be improved even without good flexibility.

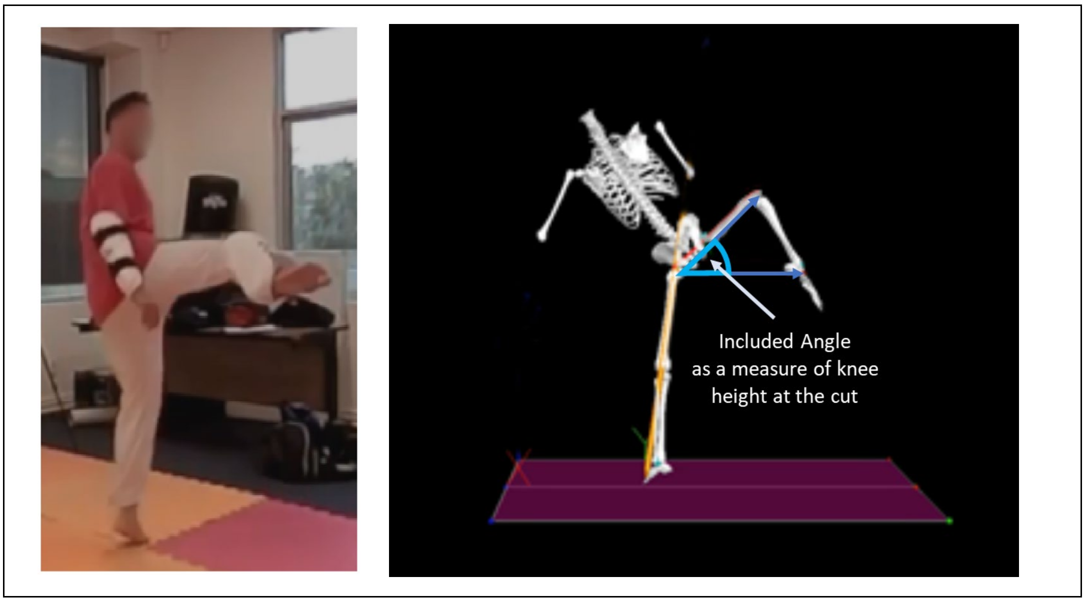


Figure 3.4: ***Hip Flexibility, Defined as Front Knee Height***

3.4.2 Balance

The coaches associated balance with the recovery after a kick, and specifically related to the supporting leg as exemplified by Coach 3: *"Like if they're asked to perform continuous roundhouse kicks to the body, we would want to check pivoting and hip turns and how they set their COG. Because if they set improperly, and they land too far in front, it's hard to throw the next kick.*" In Phase 2, the authors defined this variable as the change of foot angle from the start of the movement to impact (Figure 3.5) primarily from the description provided by Coach 4: *"But looking at his support foot, it's not 180 degrees. Biomechanically, his foot should be 180 degrees, heel towards partner. Therefore, the lateral motion of his knee and hip is forcing him to stick his bum out.*" The assessors supported the authors' description;

commenting that the distance of the target will affect the rotation of the supporting foot, especially when the target is farther away from the kicker. Coachability was deemed easy, but intermediates may need more time (Coach B: *"They may learn the skill fast in the regular distance, but maybe longer to adjust to short and long distances."*). However, they disagreed over foot position with one coach suggesting the supporting foot should be flat on the floor at impact, while the other recommended a plantarflexed ankle for better kick execution. The latter coach recommended the height of the heel from the floor as a complementary variable to measure. Both agreed that foot rotation would be easy to coach.

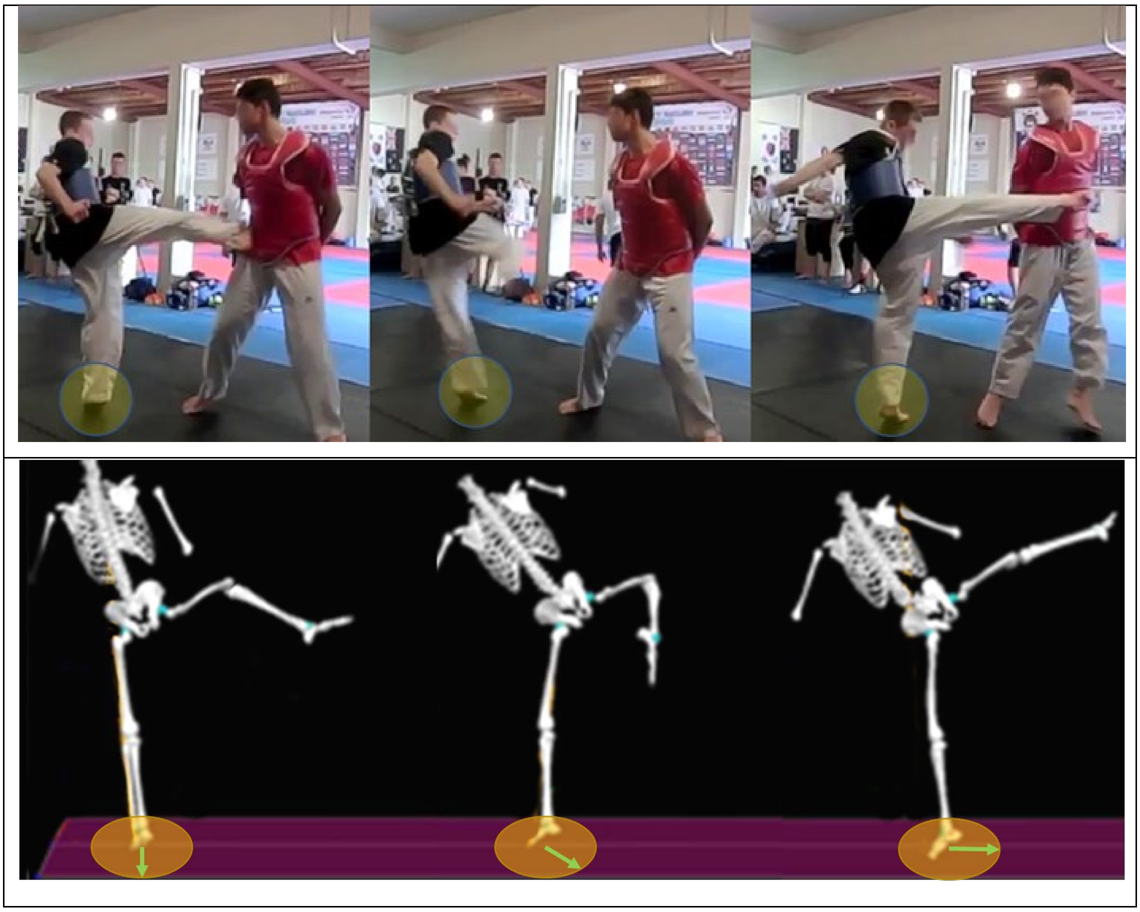


Figure 3.5: ***Balance, Defined as Support Foot Balance***

3.4.3 Control/Coordination

Control/coordination encompasses several components of the kicking combination that were supported by Coach 3: *"Main factors would be the pivoting foot. It should propel the hip action. Maybe it's simultaneous. But both should come out; the pivoting foot and the full hip throw going forward. All of this would contribute to the whipping motion.*" The last sentence concerned the sub-theme that was reiterated by Coach 1: *"He's got a better kick at him. More on the inside. More flick. Instead of straight up and down, like vertical. Or having no flick, like a baseball bat. That would be bad skill level.*"

In Phase 2, the authors focused on the "flick" mentioned by most coaches and settled on foot velocity to signify this. The flicking motion of a kick transfers momentum down the kinetic chain to create a high velocity in the distal segment. The mean velocity of the foot from the end of the cut until foot impact was selected to indicate the coordination adaptation required to achieve a scoring kick.

The assessors understood the variable very well and considered it very important for expert performance and the successful execution of the cut-roundhouse combination. Both coaches believed that the 'chamber' (i.e., hip and knee flexion) prior to leg extension was a critical factor to increase foot velocity. The interpersonal dimension was alluded to by Coach B: *"Timing is important so as not to entangle your leg with the opponent's."* An additional variable that was suggested was the angle of the foot at impact. These technical factors distinguished between intermediate and expert fighters, although the coaches thought this variable could easily be coached.

3.4.4 Distance

The coaches associated distance adjustment with the correct kicking range, as outlined by Coach 3: *"Whatever the length of your leg is, you should master that length.*" The adaptation of distance was also linked to the opponent's movements as Coach 1 indicated: *"You can tell them, if they're wasting kicks, kicks that have no chance of scoring. You can tell them, if they haven't picked it up already, if the person's staying on the spot, if they're kicking long, then you can kick short. Or if the person keeps on moving back, so put them in the corner so they stop moving back. Or you need to take a shuffle in before you kick.*"

The authors interpreted distance as interpersonal distance (IPD) and defined this as changes in the distances between the kicker and the target during the cut and kick phases (Figure 3.6). The IPD was described as the three-dimensional distance between the centre of gravity (COG) of the kicker's pelvis and that of the target on impact.[71] By measuring this distance in three dimensions the effect of differences in height can be accounted for. Using the COG of the pelvis eliminates the effect of limb motion on the total body centre of mass.

The assessors understood IPD well, and agreed it was very important in expert performance, and the execution of the cut-roundhouse combination. They spoke mostly on the tactical significance of IPD adjustment, particularly if there was a height disparity between fighters, and the appropriate use of the cut for measuring distance (Coach B: *"Shorter fighters should close the distance more, and taller ones should try to keep their distance."*). These coaches thought that IPD adjustment could be hard to coach depending on the skill level of the learner (i.e., intermediates may have more difficulty controlling distance) and fighting style (i.e., back-leg kickers may find it harder to adjust the distance).

3.4.5 Footwork

The coaches closely related footwork to distance manipulation, as indicated by Coach 3: "*Maybe a quick step in before the kick. It's like math. If you move one and the opponent moves one, so the distance is still the same. So, you need to move one and a half or two. But the speed of his one should be equal to the speed of my two, so you can connect.*" Changes in IPD are established through footwork, therefore it was considered that tracking adjustments in IPD between the phases of the kick would capture this technique feature.

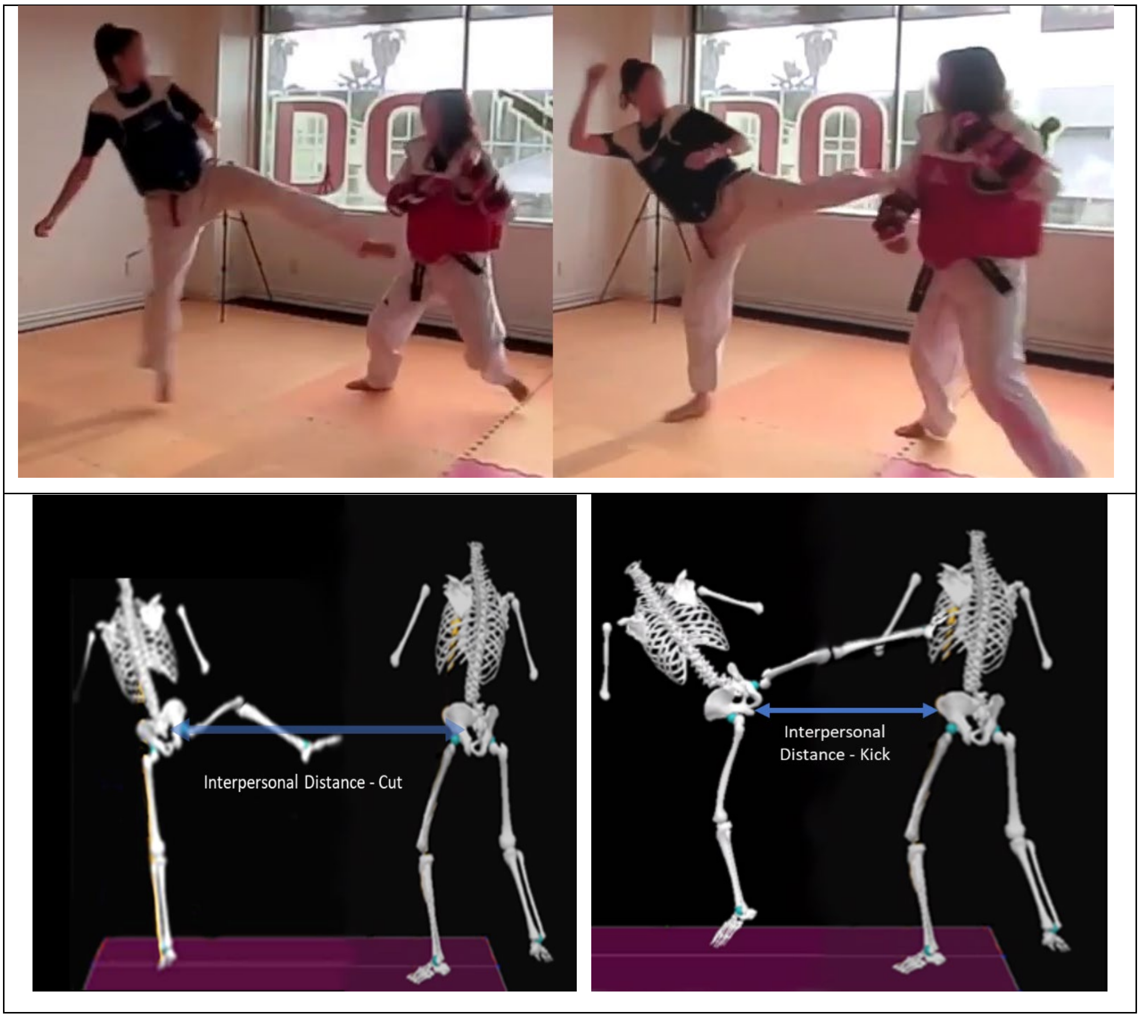


Figure 3.6: Distance and footwork, defined as interpersonal distance

3.4.6 Speed

The coaches referred to speed in general terms, but two coaches associated it with the cut-roundhouse transition, which informed the authors. Coach 1: *"The cut can be slow to get the right distance. You're putting it out like how boxers tag them (puts out arm). They can put that out slowly. But when they hit them, it's got to be good and quick.*" Another critical point raised by Coach 3 was relaxation: *"That means that your joints are very loose, and your muscles are flexible, and the whipping action and the speed of your roundhouse will be very good. Your recovery will be fast.*"

The authors concentrated on the specific time-lapse between the cut and kick. The cut-transition speed was defined as the transition speed between the end of the cut and the start of the kick, showing the changeover from the cut to the kick.

Assessors understood this variable very well. They also agreed that it was very important in expert performance and the execution of the cut-roundhouse combination. Speed is necessary to enable adjustments to the opponent's reactions and the attacker's intentions (Coach A: *"Is it a preparation? Or an attempt to score in itself?"*). One assessor surmised that it was easy to coach, but the other thought it somewhat harder to coach because of the greater balance required to deliver two effective techniques.

3.5 Discussion

This study aimed to: (1) capture expert coaches' knowledge of the critical factors of the taekwondo roundhouse kick, (2) translate the coaches' knowledge into observable biomechanical variables, and (3) extract further expert knowledge to assess the usefulness of the resulting variables. Following analysis, six higher themes emerged from the coaches: (1) hip flexibility, (2) balance, (3) control/coordination, (4) distance, (5) footwork, and (6) speed. These were supported by several sub-themes. The authors translated each theme and sub-themes into the following resultant biomechanical variables: (1) front knee height, (2) support foot balance, (3) foot velocity, (4) interpersonal distance, and (5) cut-kick transition speed. Two separate expert coaches appraised these variables in terms of understanding, importance, coachability, and differences in expertise. The following section discusses the resultant biomechanical variables by integrating expert and theoretical knowledge.

Coaches associated front knee height with cutting in preparation for a full kick. The emergence of this action was driven by competition rules and the use of the PSS.[102] As such, the action appears to be the product of task constraints unique to the competition environment. No comparable biomechanical research was found on this technique, though it bears some resemblance to the side kick. Observing the differences while executing the taekwondo side kick at different heights and distances, Snudden[158] found no associations between maximal hip abduction angles, kick velocity and execution time. In contrast, Ha and Kim[22] found significantly greater hip flexion during the chamber when comparing skilled and unskilled fighters. Moreover, it has also been suggested that reduced hip abduction, and consequently, a lower knee height, may result in a faster kick.[119] While findings with respect to speed appear conflicted, the coach comments add important context regarding the availability of other kicking options. A better performer with a high knee lift has the option to go high or low in response to their opponents' actions. In skill-related terms, a higher knee provides greater kicking affordance in response to specifying information presented by the opponent. This outcome highlights differences in perspective between sport science and coaches as well as the importance of coach-driven understanding in the development and interpretation of measurements.

Scientifically, balance is defined as the individual's ability to position the centre of mass of their body, matching with the projection of their COG, within their base of support.[80] Whereas coaches describe foot position, hip movement, and COG. As such, they describe both observed indicators of balance and relevant determining features. For support foot balance, it is clear that coaches' task-specific concepts of balance differ somewhat from biomechanically described measures. Balance in taekwondo has been previously measured by analysing the movements of the supporting foot's centre of pressure (COP) by means of a force platform.[80, 159] Fong et al.[160] contrasted the COP sway velocity between taekwondo practitioners and non-practitioners during two dynamic tasks: a forward lunge test and a step/quick turn test. The taekwondo athletes displayed better dynamic balance in both tasks.[160] This underlines the need for both representative tasks and measured variables of meaning, as COP would need some translation before becoming "coachable". Foot angle change, as depicted by the current coaches and authors, may be a more practical alternative to measuring unilateral balance as it reflects how the long axis of the support foot adjusts to stay in line with the greatest variability in centre of mass sway. Coaches would be able to detect this more easily than COP in practice and make necessary adjustments.

While coaches clearly placed emphasis on rotation, research on the impact of the support foot angle on kick performance is sparse.[77, 119, 161] Support foot rotation has been suggested to result in different effects, including a reduction in valgus-varus type knee injuries during circular kicks,[119] provide greater mobility for the pelvis during the downswing phase taekwondo axe kick,[161] and allow for pivot hip displacement while adjusting to targets at different distances while delivering the taekwondo roundhouse.[77] With the benefit of coach insight, it seems that "balance" needs to be considered through a coordinative model. Examining angle change of the supporting foot as an indicator of kicking performance seems to have potential for investigation as coupled variable in representative tasks that include opponents.

The coaches associated coordination with several components of the movement, with emphasis on the "flick" at the last phase of the kick and translated by the authors as foot velocity. Within the context of human movement, coordinated movement occurs with spatio-temporal precision, where all elements of the movement are in the right place at the right time.[46] Coordination should be maintained according to the variability of context conditions, and this is achieved by appropriately regulating degrees of freedom.[46] In taekwondo, a coordinated athlete should consistently score on opponents of different abilities and styles under differing constraints. Consequently, coordination in representative tasks is nested, possessing inter-personal as well as inter-segmental dimensions. In the cut-roundhouse combination, the two dimensions are linked by the transition time between the two techniques. A relevant task constraint here is the PSS, which requires a particular action for scoring. The PSS has been the primary determinant of scoring effectiveness in competition.[69] In the past, the sound of a kick on its non-electronic predecessor has been an indicator for scoring a point.[18] Without the benefit of the PSS during sparring, coaches should emphasise the flick by the sound it produces on the body protector. The PSS specifies a unique affordance that is most directly coupled with the end point of coordination, which is the flick or "whip." Biomechanically, the flick can be characterised as a brief impulse wherein a high force is imparted on the target over a brief time period.[162] This needs to be considered when viewing biomechanical research examining kicking techniques which almost exclusively focus on velocity and/or force.

Given the specific construction of the PSS and the layout of the sensors, accuracy is another important task constraint. It has been suggested, that to improve performance, the kicking knee should be extended as soon as possible after knee flexion to reduce lag time and utilise the stretch-shorten cycle in the knee extensors effectively increase peak velocity.[46] However, studies in soccer kicking reported a velocity-accuracy trade-off implying that kicking as fast as possible and kicking accurately are initiated by different control and movement strategies. For example, van den Tillaar and Ulvik[163] found a velocity decrement in both dominant and non-dominant legs when accuracy was the task emphasis. This trade-off was not apparent in Kim's study[46], as velocity and accuracy had a linear relationship over 10 practice sessions, although this may have been due to the novice skill level of the participants. Monitoring foot velocity in representative research designs using the PSS will yield meaningful results as the PSS remains poorly understood by most practitioners and researchers.[106]

Other research supported the coaches' concept of coordination. For instance, Kim[46] examined the effects of a practice protocol on the pattern and accuracy of the roundhouse. For the kicking leg, there was a progression in segment velocity from proximal to distal segments (trunk to knee), following the sequential pattern described by Coaches 1 and 3. The distal segments pointed towards consistent patterns while the proximal segments indicated fluctuations over the practice sessions.[46] A subsequent study on expert taekwondo athletes outlined a similar proximal-distal sequential pattern in the execution of the roundhouse kick, with the thigh achieving lower velocities compared to the foot.[164] The proximal segment also reached peak velocity earlier than the shank and the foot, suggesting the whip-like action Coach 3 alluded to. It should be noted that both studies used a static and relatively light target and may have influenced the inter-joint coordination of the kick. Using the PSS in more representative designs may reap more useful information for practitioners.

Although the current coaches used non-technical language to explain IPD, their descriptions shared similarities with skill literature. In boxing, IPD has been considered a control parameter for an attacker-defender dyad.[12, 112] This metric is "action-scaled" as the distance will change on certain action-scaled features, such as limb sizes.[12, 112] Okumura et al.[14] observed that closer IPDs slowed down kendo athletes' defensive reactions and movement times. Consequently, expert kendo practitioners remained at the "far" IPD longer than their intermediate colleagues as this distance was thought to be more associated with actual strikes and strike success frequencies. The near distance may be more ideal for defence (i.e., "crowding" the opponent to neutralise their attacks), but not for offense. A study comparing IPD adjustments between striking a punching a bag and a taekwondo competition match yielded similar behaviour to the kendo athletes.[165] The taekwondo athletes formed near and far IPD coordination trends (76% and 181% of limb length, respectively), which were different to the IPD range while striking the bag (0-168%).[165] These findings support coaches' emphasis on the tactical importance of IPD.

The coaches also described other dimensions of IPD which are reinforced by research. Coach 1 alluded to using the cut to initially explore distance instead of putting sufficient power behind the kick for a possible point. Thus, the intention behind the strike will certainly influence the adjustment of the IPD. Investigating boxing strikes, Hristovski et al.[12] proposed the perception of target strikability (i.e., the intended power behind the punch imparted on the target) as a possible constraint for striking in a dyad. Likewise, Dietrich et al.[166] included this intentionality factor, which they termed decisional and/or emotional parameters, in a general model for interpersonal interaction in aikido.

Coaches referred to footwork as the mechanism to regulate IPD for which limited support can be found in the literature. In taekwondo competition, Moenig[18] observed that at the end of the 1970s, a hopping motion of the back leg was already used to cover distance, to control the opponent, or as a feint. The hop was usually used with a front leg push-kick; a possible precursor of the current cut-roundhouse combination. Roosen[119] used a three-kick combination to observe the variability between performances in regular (i.e., training) and 100% (i.e., competition) modes. Kick 1 had the fastest movement times in both modes, and its average speed was improved in the 100% mode by increases in the distance covered in the same duration. On the other hand, kicks 2 and 3's faster average speed was achieved by improved kicking times, implying that after the initial forward drive of kick 1, emphasis shifted on movement velocity. It was pointed out that this strategy of covering more distance in the initial movement may provide more perceptual cues to the opponent, who may cut off the attack and render the rest of the combination useless. Consequently, a faster movement speed in less distance may be a better tactical alternative.[119] This coincides with the current experts' data and the resulting variables for observation, particularly foot velocity and cut-kick transition time.

In the literature, footwork is found in the umbrella term "preparatory actions." Research that profiled activities during taekwondo matches yielded limited information on preparatory movements and their association to successful scoring techniques.[20, 167] Another study that observed the tactical sequences in taekwondo matches during the London Olympics had more useful data.[168] The researchers used lag sequential analysis, in which every action (conditioned behaviour) in a chain is reliant on the preliminary action (focal behaviour). When attacks (direct or indirect) were considered as focal behaviours, the sequence was exemplified by "opening → dodges → attack (direct or indirect)." An indirect attack was distinguished from a direct one by an initial movement, such as a step, skip, guard change, kicking trajectory modification, etc., ending with an impact on the opponent. An opening would constitute of any "movement to get control of distance with the opponent or bridge the gap between both competitors" (p. 437), which may be regarded as the same movements that preceded an indirect attack. While the research did not differentiate between scoring and non-scoring attacks nor did it specify specific actions or techniques, it did highlight the tactical importance of preparatory movements to create affordances to actions. Another study used the same descriptions for direct and indirect attacks while observing university taekwondo matches.[169] Winners and non-winners performed a similar number of attacking actions, but winners counterattacked more that may have tipped the balance towards victory. Significantly, the winners completed more anticipatory counterattacks, which were matched with indirect attacks, suggesting that the preparatory movements that preceded the indirect attacks may have drawn out the opponent's reaction for a possible counterattack as observed by Menescardi and Estevan.[168] Once again, the value of preparatory movements was typified by their more frequent use by the winners. But specific tactical actions were not recorded as well as the effectiveness of these actions in this study. Future activity profiling research may benefit from expert knowledge on the most useful aspects around preparatory actions.

The authors translated the coaches' data directly to signify speed as the time-lapse between the cut and the kick. Historically, taekwondo competitions only awarded points for single strikes, following karate's philosophical concept of "one-blow – certain death" (*ikken hissatsu*).[19] However, when full contact was permitted in 1967, combinations evolved as it did not make sense to stop a fight after a flurry of strikes if it is likely to end a fight with one blow, implying knocking out the opponent.[19] However, most research on taekwondo techniques focused on single kicks, so finding support for the coaches' suppositions on the transition speed between the cut and the kick was difficult. Roosen[119] and Roosen and Pain[23] observed a three-roundhouse kick combination and measured movement time, distance covered, peak foot velocity, and impact of the three kicks. But in both studies, the lag time between techniques was not recorded. Research on activity profiling during taekwondo matches observed preparatory movements along with fighting activity, but there was no analysis on the association between these two kinds of activities.[20, 167] Additionally, only total times spent on each type of activity were recorded, preventing the breakdown of action speed and lag times between actions.[20, 167] Lag times were also absent in Menescardi and Estevan's study that examined the sequences of direct and indirect attacks and observed "opening" actions preceding these.[168] As revised competition rules penalise a prolonged cut without a quick follow-up attack,[69] coaches would want to maximise the tactical advantages of the cut as a preparatory action without costing their athletes points.

3.6 Conclusion

This study aimed to: (1) capture the knowledge of expert coaches in the taekwondo roundhouse kick, (2) translate the knowledge of the coaches into observable biomechanical variables and (3) extract the knowledge of the other expert coaches in the resulting variables to assess the usefulness of the resulting variables to present a model of cooperation between coaches and researchers. Coach-derived critical factors were broken down into six main themes that emerged from coaches: (1) hip flexibility, (2) balance, (3) control/coordination, (4) distance, (5) footwork and (6) speed. Some of these factors had strong theoretical links, but others did not. The authors translated these main themes into the following biomechanical variables: (1) front knee height, (2) support foot rotation, (3) foot velocity, (4) interpersonal distance, and (5) cut-kick transition speed. Two separate expert coaches assessed these variables in terms of understanding, importance, coachability, and differences in skill level. The coaches mentioned several practical considerations that offered a different perspective on how coordination and performance may be measured in research. These discrepancies underline the difficulties of determining what in fact are critical factors. In attempting to translate expert knowledge into biomechanical variables, we supported a process of interaction between practitioners and researchers to produce more useful knowledge. Consulting with different coaches in Phase 3 provided a methodological novelty that can be applied to future research. The resulting critical variables can therefore be understood and directly applied in context by both coaches and researchers. Greater cooperation will certainly benefit both parties by progressively developing a common language.

Subsequent investigations involving the variables in the current study can solidify them as critical factors in roundhouse performance. Also, it would be enlightening to seek the knowledge of more taekwondo coaches, as well as experts in other combat sports, to guide research questions in the future. In particular, they could aim in making research designs more representative to ensure more useful results. Future activity profiling research may also include information around technique combinations and preparatory actions that are useful to coaches. Coaches can focus on the variables in this study when designing learning environments. For instance, variability in the distance and movement of kicking targets may assist learners to adapt their balance, IPD, and foot velocity more effectively to score more consistently. Exploring the effectiveness of such pedagogies would be a fruitful avenue in the future.

3.7 Bridging Statement

The study presented in Chapter 3 produced candidate critical variables for the performance of the taekwondo roundhouse kick. Some of the coach-determined variables have theoretical basis and thus were relatively easy to translate into biomechanical variables. But some have little footing on research and translation was more challenging. However, the study presented in Chapter 4 hopes to provide experimental support for these variables by investigating expertise-related differences in variability. Chapter 3 provided the first step for a model for coach-scientist cooperation that could be used in the future. This next study would be the second step.

CHAPTER 4

EXPERTISE-RELATED DIFFERENCES DUE TO INCREASED TASK REPRESENTATIVENESS FOR A TAEKWONDO ROUNDHOUSE KICK COMBINATION

This chapter comprises the following manuscript:
Bercades, L. T., Oldham, A., Lorimer, A., Millar, S.-K., & Sheerin, K. (2022). Expertise-related differences due to increased task representativeness for a taekwondo roundhouse kick combination

4.1 Preface

The study within this chapter is an attempt to affirm the coach-researcher model of cooperation in Chapter 3. Some literature was presented in Chapter 2 supporting the identification of critical variables of kicking skills by comparing performance variables between expertise groups. Chapter 4 aims to build on this research by using the coach-scientist-determined variables from Chapter 3. Furthermore, a representative research design was used in the study in Chapter 4 to establish the "ecological generality" of the findings.

4.2 Introduction

Representative research design considers the ecological aspects of the phenomenon being investigated to establish the 'ecological generality' of a result.[6] The term 'representative' was originally defined as the organisation of factors (or constraints) in an experimental design that reflect the behavioural setting to which the results are meant to apply.[5, 6] The process requires sampling constraints from specific performance environments that preserve perceptual and behavioural cues in order to regulate the performer's actions.[6] Studies in sport sampled information such as the presence of an opponent[94, 124] and induced variability,[45, 170] to regulate the performer's actions. Therefore, research designs that reflect actual performance constraints can lead to more effective understanding of sport technique and allow for better development of training tasks to achieve movement goals.[101] A route to capturing representative performance environments may be found in expert coach knowledge.

Coaches are expected to make observations of athlete's technique and offer directions that improve performance in a coaching context. In order to do this effective coaches must possess knowledge regarding essential or critical variables that warrant attention.[37] These variables may be argued to underpin successful performance of a movement.[27] A critical variable reflects the qualitative features of a movement's coordination pattern by condensing the relationships between the pattern's components to a single variable.[26, 46, 171] Expert knowledge has been sought to identify the critical variables for skills such as the volleyball spike,[28] sprint running,[29] rowing,[31] and the taekwondo roundhouse.[34, 172] Efforts have been made to use expert coaches' experiential knowledge to strengthen theory or drive research questions in practice.[30, 31, 35, 36, 63, 64, 172] The term 'coaching-biomechanics interface' has been used to describe this collaboration.[35, 37] As part of this interface, coaches' knowledge is combined with scientific concepts to help understand and quantitatively capture specific sports technique. A small number of studies have used the experiential knowledge of expert coaches and athletes to reinforce theoretical knowledge,[30, 31, 35, 36, 63, 64, 172] but few have used coaches' knowledge to guide subsequent research.[35, 36, 95, 172]

Another strategy to identify critical variables in movement coordination research is to compare different levels of expertise. Here, previous research has yielded inconsistent results, with some identifying clear distinctions based on expertise,[39, 40] while others found no differences.[43, 173] One study investigated various joint couplings during the volleyball serve in order to determine if expertise related to a clear distinction between stages of learning.[26] The relationship between the shoulder and wrist coordination emerged to be the critical variable to summarise differences between skill levels. However, the critical variable followed a succession of coordination states that distinguished between expertise groups instead of an 'all-or-none' difference.[26] This invites questions about the suitability of traditional analysis methods when looking at complex skilled movements.

In contrast to more traditional methods, ecological dynamics characterises movement expertise in terms of variability. Experts are thought to demonstrate greater movement variability during a task, with more stable task outcomes.[43, 83] Movement variability is considered functional as it allows for more flexibility for movement adaptation and error correction during skill execution and learning progression.[9, 83] Coordination variability has been described to have a U-shaped curve when related to skill and consequent performance.[93] That is, less skilled performers displayed greater random variability, while those with intermediate skill had decreased variability, and highly skilled performers showed greater functional variability. As such, the nature of variability within different expertise levels may be a more useful consideration than the differences in magnitude. When variability occurs randomly (termed stochastic), each possible outcome is equally likely to happen.[92] As there are difficulties with the concepts and quantification of randomness and stochasticity,[92] the current research will focus on movement variability through coefficient of variation (CV) which approximately captures this phenomenon.[96] Differences in movement variability have been examined between participants of different expertise levels in the past,[93, 95-97] but no research could be found on striking actions in combat sports.

With respect to researching representative tasks and expertise, dyads may be beneficial as most, if not all, variables, are represented within the system. This research design[6] has been used in basketball[94] and combat sports[13, 174] Coordination in combat sport is nested, possessing inter-personal as well as inter-segmental dimensions (i.e., interactions between the angles and velocities of related joints). A viable example of this is taekwondo, a traditional Korean martial art that features striking with the hands and feet and has been an official Olympic sport since 2000.[17] Competition rules have been continuously revised, necessitating frequent adjustments of techniques and tactics.[67, 71, 77, 100, 175] The roundhouse or turning kick to the torso (*dollyeo-chagi*) is the most common attacking technique in taekwondo competition.[20] Identifying the critical variables of the roundhouse kick is a necessary task in instruction and coaching to adapt to constant rule changes. While some expert knowledge has been gathered on its critical variables,[34] most of the research on the kick observed coordination or kinematic and outcomes determined by researchers.[67, 71, 77, 100, 175] With the taekwondo roundhouse, experts may demonstrate more variability in critical variables while still scoring consistently in competition contexts.

Some taekwondo research has investigated differences in certain variables between expertise groups,[85, 87] but variability itself was not explored. Recent research on taekwondo kicks has moved towards representative research design,[23, 24, 104] with Maloney's work explicitly exploring this approach.[13, 108, 118, 165] Despite the dynamic nature of taekwondo competition combat, it has been commonplace to examine the roundhouse kick while participants strike a static or fixed target[71, 78, 98] or no target at all.[78] Additionally, when full contact was permitted in competition in 1967, striking combinations evolved.[19] However, research has more frequently been conducted using isolated kicks.[23, 119]

This study aimed to examine expert-intermediate differences in coach-identified critical variables using a representative design. In this manner, the usefulness of the coaching-biomechanics interface in skill research may be explored. Given the preceding theoretical influences, we propose that: variability of the critical variables will be different between expert and intermediate athletes and the differences in variability between expertise groups will grow as the representativeness of the task increases.

4.3 Methods

4.3.1 Participants

Six intermediate and five expert taekwondo fighters participated in this study. In accordance with previous research, experts were defined as having a minimum of 10 years competition experience and intermediates no more than six months. [26, 96] Due to the technical nature of the kicking combination being observed, and the desire to ensure the safety of all participants, only athletes with at least intermediate competition experience were included. Sample estimation using GPower based on results from Pozo, Bastien & Dierick (2011) and Estevan & Falco (2013) specified an overall sample of 10 or above, thus this sample was deemed sufficient.

To verify respective levels of expertise, analysis of group differences with respect to scoring on the PSS was performed, unexpectedly these yielded no significant differences. Instead of proceeding with an artefactual analysis of group differences, participants were instead allocated to groups via median split of dynamic target (DT) scoring, as the authors considered the DT condition being most representative of the performance context and relevant expertise. Participant demographic data and scoring averages were recorded. The characteristics of the participants in their adjusted groupings are presented in Table 4.1 below.

Table 4.1: ***Participants' Characteristics***

	Intermediates (*n* = 6)	**Experts (*n* = 5)**
Age (years)	22.50 (10.75)	22.60 (10.50)
Practice years	11.00 (8.58)	8.00 (2.15)
Competition years	8.50 (8.50)	5.90 (2.79)
Height (cm)	161.25 (14.41)	173.86 (8.50)

Body mass (kg)	56.12 (18.09)	64.06 (7.48)
Leg length (cm)	76.03 (10.48)	90.72 (2.97)
Scoring average-static	0.58 (0.24)	0.63 (0.15)
Scoring average-dynamic	0.31 (0.07)	0.56 (0.13)

4.3.2 Procedure

After a 10-minute warm-up, including time to practice the combination on the Protector & Scoring System (PSS) (Gen1, Daedo, Barcelona, Spain), each fighter performed a cut-roundhouse kicking combination. The combination begins with the 'cutting kick' or 'cut' which is a preparatory action involving a hop forward with the rear (supporting) leg while doing a push-like kick involving the simultaneous extension of the hip and knee. This is followed by the roundhouse kick, which is characterised as a throw-like movement defined by hip flexion followed by knee extension.[77]

Participants performed as many kicks as necessary to achieve five scoring kicks under the following conditions in a randomised order: no target (NT), static target (ST), and dynamic target (DT). For the ST and DT conditions, the fighters kicked an opponent wearing the PSS. The PSS was calibrated based on each participant's weight division, gender, and age/competition bracket. Only the kicks that activated the PSS were analysed. Each participant was allowed 10-30 seconds rest between trials and 30-60 seconds between kicking conditions. Scoring averages were calculated by dividing the number of scoring kicks by the total number of attempts.

Table 4.2: ***Kicking Conditions***

Kicking condition	Details
No target (NT)	The participants were instructed to perform the combination at the same speed and intensity they would in competition.
Static target (ST)	The target consisted of the first author wearing the PSS in a stationary ready stance.
Dynamic target (DT)	The PSS-armoured researcher slid backwards away from the participant to simulate an indirect attack by the participant (i.e., a preparatory movement [the cut] and the attack [the roundhouse]).

Kinematic data were measured using a 9-camera three-dimensional (3D) motion analysis system (Vicon, Oxford, UK), sampling at 200 Hz. Retroreflective markers (10 mm) were attached to specific anatomical landmarks as detailed in Figure 4.1. Clusters of four markers, on thermo-moulded plastic shells, were attached to the thigh and shank. Pelvis and torso markers were also affixed on the opponent. Following a static standing calibration, the femoral condyle and malleoli markers were removed. For dynamic calibration of the hip joint, the participants performed a combination of flexion, abduction, adduction, and extension movements on each leg. Three shallow squats were performed to calibrate for the knee joint centre.[176] Anatomical co-ordinate systems were defined according to specifications reported by Besier et al. (2003).[177]

Figure 4.1: ***Marker Placements for Kinematic Analysis***

4.3.3 Data Processing and Interpretation

Raw kinematic data was imported into Visual3D (C-Motion Inc, MD, USA) and applied to a custom model with an additional pelvis and torso for the target for the static and dynamic trials. Standard Visual 3D inverse kinematic constraints were applied to the hip, knee, ankle torso, shoulder, and elbow joints. Marker signals were filtered with a single bidirectional 15Hz low pass Butterworth filter. Velocity of the foot segment, hip angle, knee angle and pelvis displacement and velocity were extracted from the modelled data. The roundhouse kick technique was sub-divided into seven events that were identified from velocity-time curves of the centre of mass of the kicking foot segment. The observed variables were translated from previously determined expert knowledge from Chapter 3 and defined below in Table 4.3. Data were discarded when insufficient marker data were present to make reconstruction possible.

Table 4.3: ***Kicking Events and Candidate Critical Variables***

Candidate critical variables	Kicking events	Biomechanical variable
Support Foot Balance	1. Start: The point when the kicking knee began to lift vertically in the Z axis.	Foot angle change: The change of foot angle from the start of the movement to impact. Differences in foot angle were observed from the Start to the Contact Kick events
Front Knee Height	2. Max Knee Cut: Instance when kicking knee at its highest vertical point during the cut.	Front Knee Angle: Expressed as the angle between the supporting leg and the kicking leg at maximum hip flexion

		during the cut and during the kick (Figure 3.4).
Cut to Kick Transition Speed	3. Contact Cut: The point immediately after Max Knee Cut when the kicking foot stopped (i.e., zero velocity) in the anterolateral direction.	Transition Speed: Calculated between the Contact Cut and Kick Commit events, which implied a clear change from the preparatory cut to the attacking kick.
	4. Change of Foot Direction: In which the kicking foot changed direction in the anterolateral direction indicating the transition from the cut to the kick.	
	5. Max Knee Kick: The highest vertical point of the knee upon the initiation of the kick.	
	6. Kick Commit: The point where the kicking hip moves from external to internal rotation indicating the shift from the cut to the kick.	
Foot Velocity Interpersonal Distance	7. Contact Kick: The point after Max Knee Kick where the foot velocity stopped in the anterolateral direction indicating contact with the target, or the termination of the kick during the no target trials.	Foot Velocity: The mean velocity from the Change of Foot Direction to the Contact Kick events was selected to indicate the coordination adaptation required to score on the PSS. Interpersonal distance (IPD): Defined as the distance between the centre of mass of the kicker's pelvis and the centre of mass of the target's pelvis at the start, cut and kick, centre of the knee position with respect to the laboratory

		coordinate system (Figure 3.6).[77] All distances were scaled to the participants' individual leg lengths.[12]

4.3.4 Statistical Analysis

Data were cleaned and Coefficients of Variation (CV) were calculated by dividing the standard deviation by the mean of the variable of interest for primary analysis.[96] The CV measures the variability of a series of data independently of the unit of measurement used,[178] making it an appropriate omnibus test for the different variables observed in this study. Using the CV allows the ratio between SD and mean constant while allowing both to vary.[179] Therefore, SD was used in this study as a subsidiary confirmatory test because it was a more informative index of coupling. A two-way repeated measures ANOVA Group (Expert/Intermediate) by Target (NT/ST/DT) was performed for each variable of interest. Significant differences were followed up with pair-wise *t*-tests and calculation of effect sizes (Hedge's g). Where significant effects were found, subsidiary analyses were undertaken on respective means and standard deviations that underpinned the relevant CVs. Assumptions of sphericity were examined using via Mauchly's test, normality was examined via Levene's test. All assumptions were met throughout the analysis phase.

4.4 Results

The descriptive statistics of all the variables are presented in Table 4.4. In terms of variability, significant results by kicking condition and group are presented in the following sections.

Table 4.4: ***Descriptive Statistics***

Variable	Intermediates (*n* = 6)						Experts (*n* = 5)					
	No target		Static target		Dynamic target		No target		Static target		Dynamic target	
	M (SD)	CV M (SD)	M (SD)	CV M (SD)	M (SD)	CV M (SD)	M (SD)	CV M (SD)	M (SD)	CV M (SD)	M (SD)	CV M (SD)
Foot angle change	41.81 (19.98)	-0.33 (2.13)	53.33 (46.11)	0.50 (0.33)	57.11 (59.67)	0.57 (0.28)	24.55 (12.84)	0.37 (0.17)	31.30 (28.17)	0.52 (0.33)	27.14 (13.78)	0.47 (0.22)
Front knee angle at the cut (normalised)	0.32 (0.13)	0.16 (0.06)	0.32 (0.06)	0.12 (0.06)	0.33 (0.06)	0.13 (0.07)	0.26 (0.09)	0.18 (0.04)	0.30 (0.03)	0.09 (0.04)	0.28 (0.03)	0.07 (0.03)
Front knee angle at the kick (normalised)	0.24 (0.12)	0.37 (0.29)	0.36 (0.07)	0.30 (0.24)	0.28 (0.05)	0.22 (0.19)	0.21 (0.10)	0.28 (0.17)	0.29 (0.13)	0.24 (0.17)	0.29 (0.15)	0.14 (0.08)
Transition speed (*m/s*)	0.18 (0.13)	0.20 (020)	0.19 (0.13)	1.21 (2.35)	0.20 (0.10)	0.12 (0.06)	0.12 (0.05)	0.10 (0.04)	0.15 (0.05)	0.40 (0.26)	0.13 (0.04)	0.16 (0.19)
Foot velocity (z-score)	0.09 (0.94)	0.18 (0.75)	-0.11 (0.59)	0.31 (0.92)	-0.01 (0.61)	0.49 (1.19)	-0.09 (0.93)	0.78 (0.98)	0.15 (1.23)	0.99 (2.15)	0.04 (0.89)	2.98 (6.72)
IPD at the cut			1.05 (0.10)	0.29 (0.17)	1.06 (0.14)	0.06 (0.18)			1.10 (0.08)	0.04 (0.01)	1.09 (0.09)	0.03 (0.02)
IPD at the kick			0.87 (0.07)	0.04 (0.03)	0.86* (0.21)	0.27 (0.56)			1.01 (0.11)	0.08 (0.05)	1.08* (0.20)	0.05 (0.02)

* $p = .026$

4.4.1 Front Knee Angle at Cut (Normalised for Leg Length)

Regarding the coefficient of variability (CV), we observed no main effects for group, or any significant interaction. There was, however, a main effect for target, F (2, 18) = 8.30, p = .003, η_p^2 = 0.480. Follow-up t-tests revealed significant differences between the NT condition and both the ST and DT conditions but not between the ST and DT conditions: NT-ST, t (10) = 3.105, p = .011, g = 0.900; NT-DT, t (10) = 2.676, p = .023, g = 0.776.

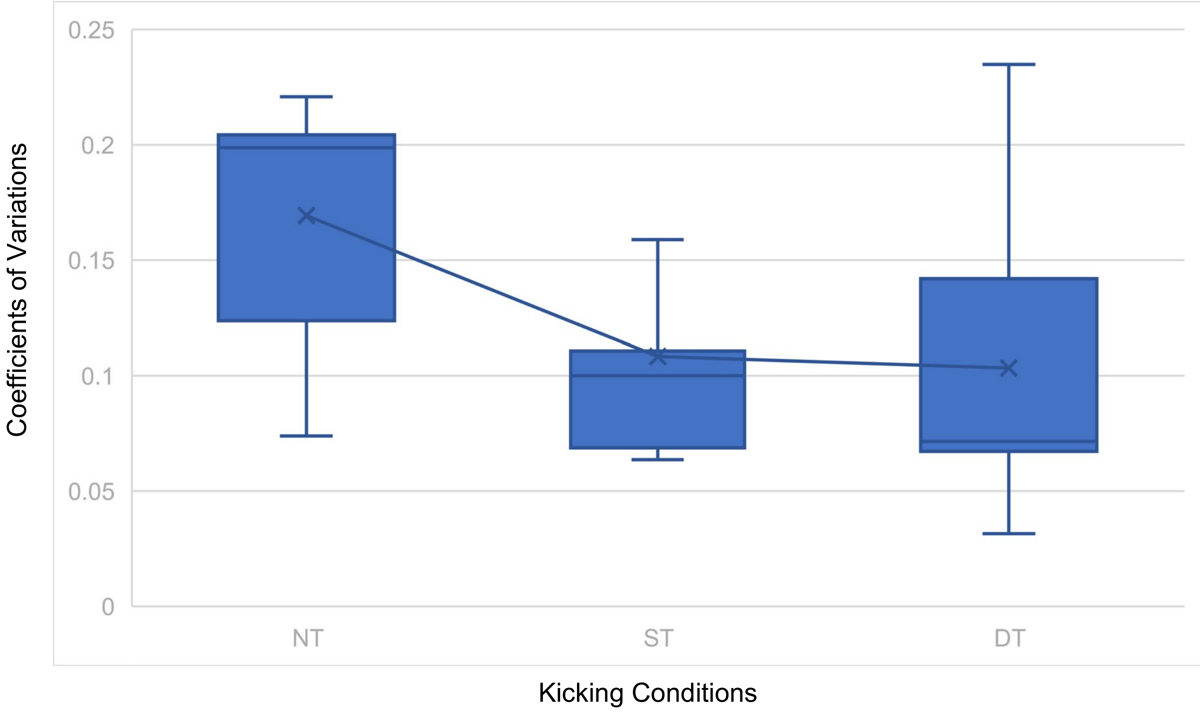


Figure 4.2: ***Front Knee Angle at Cut Coefficient of Variability (normalised for leg length)***

Subsidiary analysis of SD and absolute values also indicated that the effect was significant with respect to target only, F (2, 18) = 6.09, p = .010, η_p^2 = 0.404. Follow-up t-tests showed the same pattern of difference between means: NT-ST, t (10) = 3.076, p = .012, g = 0.17; NT-DT, t (10) = 2.36, p =.040, g =0.02.

4.4.2 Front Knee Angle at Kick (Normalised for Leg Length)

Concerning CV, there was a main effect for target and no evidence of an interaction or group difference, F (2, 18) = 4.14, p = .033, η_p^2 = 0.315. Follow-up t-tests showed that the DT condition was significantly less variable than either the ST or NT conditions: NT-DT, t (10) = 2.661, p = .024, g = 0.185; ST-DT, t (10) = 3.391, p = .007, g = 0.088.

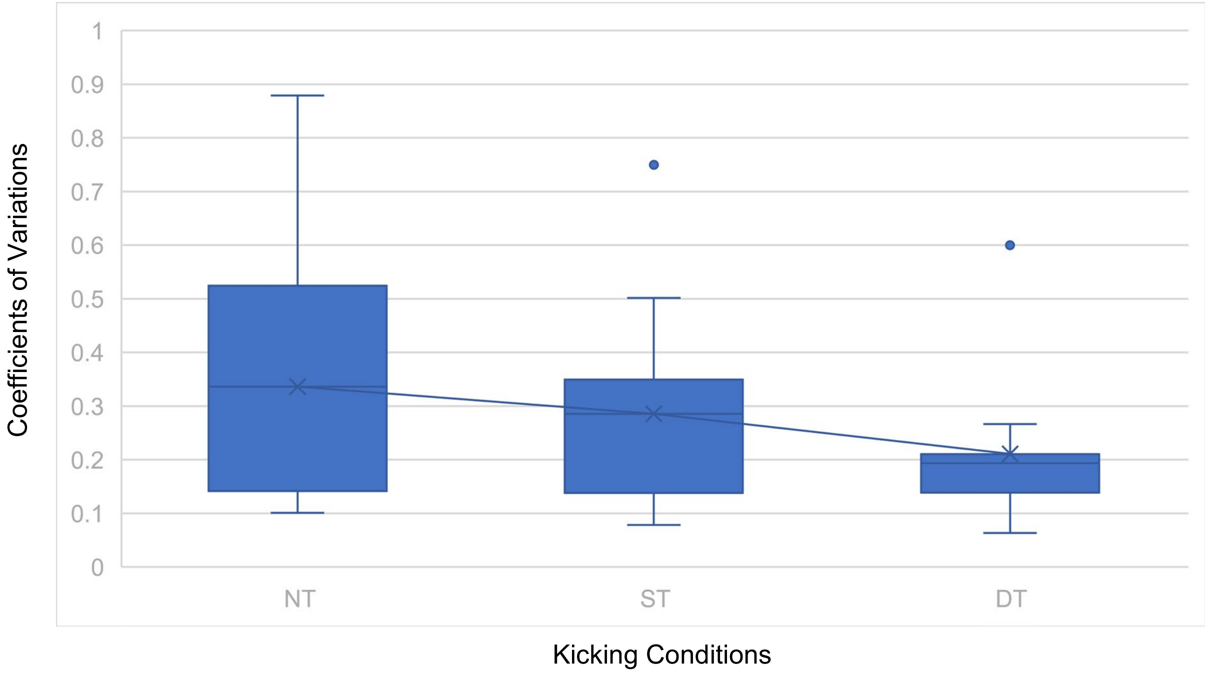


Figure 4.3: ***Front Knee Angle at Kick Coefficient of Variability (normalised for leg length)***

In the subsidiary analyses, SD showed the same pattern as CV with slightly more robust results, F (2, 18) = 4.28, p = .030, η_p^2 = 0.323. Follow-up t-tests reflect similar significant differences as CV: NT-DT, t (10) = 2.365, p = .040, g = 0.052; ST-DT, t (10) = 3.726, p = .004, g = 0.033.

Analysis of the absolute values for knee angle at kick revealed a less similar pattern with respect to target, F (2, 18) = 4.51, p = .026, η_p^2 = 0.334. The only significant result supported by the follow-up tests was between the NT and ST conditions, t (10) = -3.397, p = .007, g = 0.099.

4.4.3 IPD at the Cut

Preliminary analyses of CV showed a main effect for target, F (1, 9) = 8.649, p = .016, η_p^2 = 0.490 and an interaction for group and target which was robust with moderate effect sizes, F (1, 9) = 9.678, p = .012, η_p^2 = 0.518. Follow-up tests revealed that CV was greater for DT than ST in the intermediate group compared to the experts, t (5) = -4.855, p = .005, d = -0.524. There were no significant differences among the experts between kicking conditions, p = 0.460, t = 0.106, df = 4. Additional analysis of the interaction revealed that while both the groups were similar in the static condition the intermediate group showed significantly greater CV in the dynamic condition than the expert group (0.005, es 1.98).

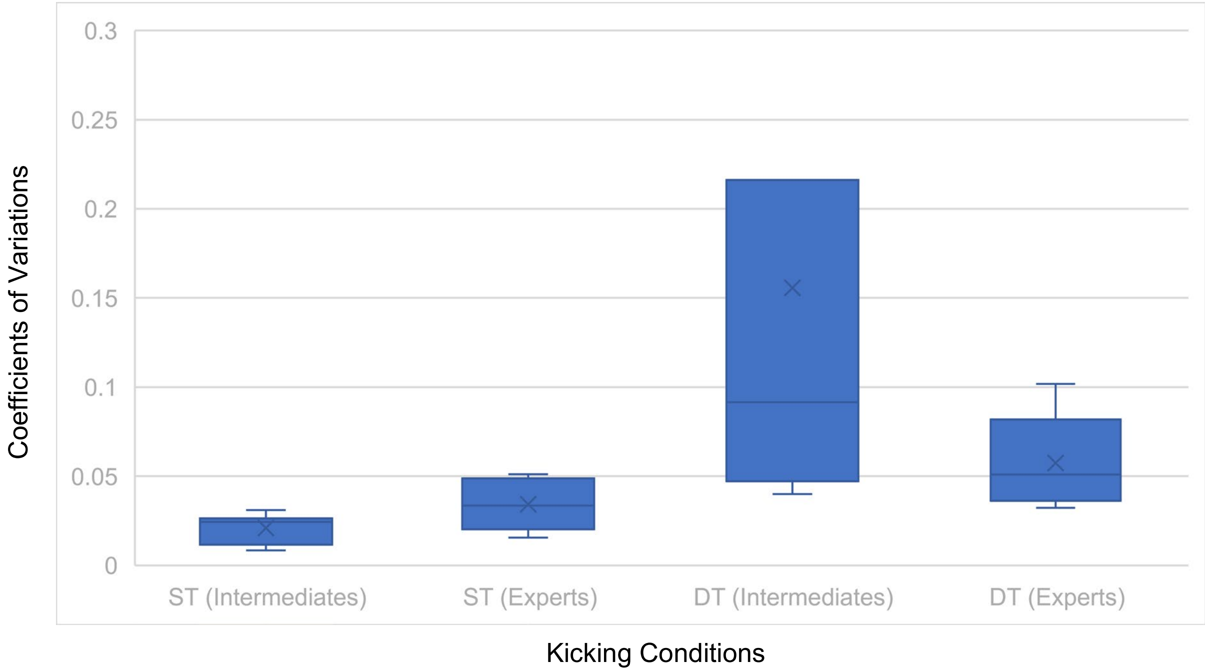


Figure 4.4: ***Interpersonal Distance at the Cut Coefficient of Variability***

Subsidiary analysis showed that a main effect for target was specific to variability (SD) and that no significant differences in absolute values were found, F (1, 9) = 7.386, p = .024, η_p^2 = 0.451. The interaction of group and target was also significant with respect to SD, F (1, 9) = 10.320, p = .011, η_p^2 = 0.534. Follow-up tests showed marginal significance between ST and DT conditions in the intermediate group, p = 0.55, t = -2.174, df = 10, g = -0.631, d = -0.656. Differences within experts were not significant, p = 0.396, t = 0.282, df = 4, g = 0.114, d= 0.126.

4.5 Discussion

This study sought to examine the utility of expert-identified critical variables with respect to expert-intermediate differences under more representative conditions. In this way, we wanted to determine whether the coaching-biomechanics interface is a useful platform for skill research. Specifically, we hypothesised that expert-intermediate differences would increase according to representativeness and that experts would have different variability to their intermediate counterparts in the presence of a more representative target. Variables for discussion that showed marginal significance and moderate effect sizes were selected that were taken as evidence of interaction as the basis for an expert model. Contrary to expectations, variability in the normalised front knee angle at the cut reduced when a target was present. Similarly, the variability in the normalised front knee angle at the kick dropped in the presence of a dynamic target. Intermediates were more variable than the experts with respect to variability in IPD at the cut. Although these variables may not have produced expected significant differences, they might reflect responses to applied pedagogy in the following study. In this sense, exploring movement through the coaching-biomechanics interface and a representative research design appear to have been moderately successful.

The design used in this study yielded coordination differences as the degree of representativeness changed. Unlike past works on cricket[8, 101] in which coordination differences were observed with or without specifying information from the environment, this study explored changes in static and dynamic conditions as well. Moreover, differences due to changes in representativeness give us more understanding of the importance of affordances to perception-action coupling. The performer-environment relationship is mediated by the performer's direct perception of the 'values' and 'meanings' of things in the environment (affordances),[7] coupling between suitable affordances and action produces functional movement solutions. [5, 7] In combat sports that involve striking techniques, a significant factor that creates affordances is the IPD of the fighter-fighter dyad.[108, 112] The IPD regulates the actions and intentions of the performer as it relates to the perception of target 'strikability'.[12, 112] During a fight, fluctuations in the IPD are contingent on the defensive/offensive interactions of the fighters. Here, affordances were absent in the NT condition. In the ST condition, only the kicker adjusted their IPD and generated their own affordances. While in the DT condition, affordances were mutually generated by the kicker and opponent as both adjusted to IPD fluctuations, as found in performance contexts. These differences had some effect on variability while changes in absolute values were less apparent, this has implications for both design and analysis of tasks in the future.

In the present study, the criterion for kick success was scoring on the PSS, perhaps the most representative way to measure kick effectiveness as it is now used widely in taekwondo competition. This was the primary consideration in distinguishing between expertise levels for analysis in the present study. Years of training and competition apparently did not effectively determine expertise of the participants as it may have been influenced by the context of practice (e.g., time spent in sparring with the PSS and the imposition of traditional techniques instruction) and competition (e.g., number of competitions that required the PSS and success in those competitions). It was difficult finding research using the PSS while investigating taekwondo kick coordination. While some studies did not measure kick effectiveness at all,[77, 104] others used the subjective assessment of the participants to determine the kicks for analysis.[180] Impact force and execution time have also been used as measures of kick quality,[81] along with velocity as a measure of improved kicking.[181] Yet another study computed kicking success score rate from impact force.[87] Here, coaches directed our search toward foot velocity which might be considered in line with previous work. However, no significant results were revealed for this variable. While we would maintain that the PSS essential to understanding kicks in context it seems that scoring on the PSS is a complex affordance not easily captured by isolated variables.

Of the seven coach-identified variables measured here, three revealed marginal significant results. Thus, expert coach knowledge might be seen as a modestly useful tool, while bearing in mind the small sample sizes used in this study. The front knee angle at the cut was identified previously by experts in Chapter 3 as a factor that allows the fighter to choose from a greater diversity of attacking techniques according to the affordance offered by the opponent. The relative higher variability of the front knee angle at the cut and at the kick in the NT condition may be an indication of greater exploration without a specifying target. Kicking in the NT condition is a regular practice task in taekwondo, such as in the performance of *hyung* (forms), suggesting a function for this task. The ability to control the lower leg during no-target kicking by way of greater antagonist activation[182] may be beneficial in the coordination stage of learning where novices construct a pattern to achieve skills at a basic level.[4] It was difficult to find similar research on expertise differences in combination kicking within different degrees of representativeness. However, similar intersegmental coordination was found in taekwondo kicks performed without a target and three types of static targets, though variability was not observed.[78] The authors surmised that the participants were already familiar with the kicking technique, which remained stable regardless of the presence or lack of a target.[78] However, the level of expertise of the participants was not described, making associations with expertise difficult. In contrast, expert karate athletes demonstrated different intra-limb coordination between impact and no-impact roundhouses.[76] Although variability was not measured, the participants regulated control of the entire striking limb instead of solely the lower leg to decelerate the limb prior to contact.[76] That study compared roundhouse kicks of different levels (i.e., with impact to the torso and no-impact to the head) and may limit comparison to the present results. In the present study, one potential reason for the similar variability between the two expertise groups is that the scoring average in the DT condition may not have been a sufficiently sensitive criterion to distinguish expertise. Hence, all the participants may have explored a similar necessary bandwidth of movement variability, similar to the basketball players of different expertise performing the free throw.[183]

The lower variability of the front knee angle at the cut and at the kick seems contrary to results of past research on interceptive tasks. Work on the table tennis forehand drive showed a funnelling pattern, in which variability was reduced from the beginning to the end of the kinetic movement chain, i.e., from the start of the swing towards bat-ball contact.[97] The pattern persisted in novices and experts in some of the kinematic variables measured, but some displayed greater variability. This control pattern may be a result of greater accuracy of perception as the target looms closer. This is in keeping with interceptive studies examining stride length during the approach phase of the long jump (e.g., Scott et al.[184]) wherein non-long jumpers demonstrated a decreasing trend of variability similar to that of elite and novice athletes. Variability was highest at the start of the approach and reduced as the participants moved toward the take-off board, which may indicate the strategy of visual regulation.[184] In the cut-roundhouse combination, variables around the cut and the early part of the kick may provide aids for visual regulation to determine the intention for the following kick; whether to deliver a roundhouse to the torso or the head, or another kick entirely, or not to kick at all. However, the results did not confirm the funnelling pattern of control from past research, which may cast doubt on whether these variables are indeed critical to performance. Or the design simply lacked power in terms of number of participants and number of trials observed. Future research should address these limitations.

Carson, Collins, and Richards (2014)[83] summarised key points about the role of intra-individual movement variability while learning a skill. Expertise can be characterised by stable task outcomes associated with greater movement variability. While there is a notion that greater control over the degrees of freedom of a movement pattern represents greater skill, there seems to be a greater collaboration between the stability of a skill to achieve consistent task outcomes and the flexibility for error correction and adaptation during the progression of learning. However, when a performer decides to focus on a particular aspect of a movement, the increased conscious control results in more consistency and lower variability.[83] In this context, the lower variability of the front knee angle at the cut and the kick in the targeted conditions may point to the participants' greater conscious control over the coordination pattern. The unfamiliar environment of the laboratory, paired with the pressure of scoring on the PSS, may have resulted in greater conscious control (and reduced variability) among the participants. Additionally, the declining trend of variability is an indicator of task-specific visual regulation previously seen in high jumpers of varying expertise.[184] However, while the use of visual regulation was evident in all levels of expertise, accuracy at the high jump take-off seem to improve with specific task training.[184] Therefore, representative taekwondo training with the presence of dynamic targets is recommended to improve the coupling between visual regulation and coordination.

Coordination variability has been described to have a U-shaped curve when related to skill and consequent performance.[93] High variability may be an indication of greater random exploration by novices, while the low variability among intermediates may imply greater coordination stability. Greater variability among experts suggests more adaptability to performance conditions. The similarity of the knee angle at the cut and kick of the two expertise groups could suggest that the participants may have similar skill levels as determined by the two variables.

Experts differed from intermediates with respect to the IPD at the cut but not the IPD at the kick. The implication of this appears to be that experts made better use of early information in the DT condition. This is in keeping with other studies that show experts are more able to couple with flight/movement information.[8, 101] Additionally, the experts' variability was more stable across both kicking conditions than the intermediates, indicating that movement variability has settled down and that IPD at the cut effectively differentiated between expertise levels. Conversely, if variability of the IPD can be considered an indication of the athlete's exploration of the combination's degrees of freedom, then the intermediates' greater magnitude could indicate the need to better attune to critical information presented by the target.[2, 4] In fact, their lower scoring success in the dynamic condition might suggest that the performers were not able to fully exploit the perception-action coupling despite the greater exploration during the cut event. From these results, it appears that the cut-roundhouse coordination should be optimised for performance contexts because long lag times between the cut and the kick are now penalised in competition;[69] thus, early adjustments to the IPD is preferred. Therefore, it could be suggested that more practice time might be allotted to performing kicking combinations on PSS-outfitted dynamic targets.

As research on the cut-roundhouse combination was scarce, studies on the IPD of isolated striking techniques are related to the results here. Research on boxing and taekwondo investigated the influence of the scaled distance to the target to the emergence of striking solutions.[12, 13, 45, 165] It was proposed that the target's 'reachability' was a probable control parameter to inform the attacker to strike and which technique to throw.[166] A control parameter is a variable that influences the order parameters of a coordination system between two fighters even though it does not contain specific information about the organisation of the system.[116] Order parameters are the variables that cover the collective information for the organisation of the pattern.[116] In boxing, the direction of fist-target impact is most likely an order parameter that determines the path of different punches.[12, 45] However, comparing striking behaviour on the punching bag as used in these previous studies to actual fight behaviour revealed that striking the bag did not represent how fighters attacked in competition.[13, 165] Findings from these studies and the present one emphasise the value of sampling key affordances from competition when designing practice and research. In future research, exploring expert (coaches and athletes) perception of the key information sources in offensive and defensive scenarios will produce insights in both practice and theory.

The coaching-biomechanics interface has demonstrated benefits in this study by showing the utility of three critical variables previously identified by expert coaches. As observed earlier in Chapter 3, the translation of expert knowledge to theoretically driven variables may be imperfect because of research and technological limitations. As with the variables observed, the choice of the analysed kick for this present study was also based on the advice of an expert coach (L. Campbell, personal communication, January 12, 2015). It should be noted that research may need to focus on popular or most used components of movements used in competition. Tornello et al. (2014)[167] indicated that rear-leg kicks are used more frequently by winners and non-winners in competition; but no data on kicking techniques were provided. Despite the scarcity of research on the matter, almost all of the research reviewed observed the rear-leg roundhouse; the classical way of performing the kick in taekwondo instruction. Predictably, kinematic differences have been found between the front-leg and rear-leg roundhouse kick.[73] Therefore, the generalisability of past research to current practice could be put into question, especially with the extensive use of front leg kicks in competition.[140] Here, expert knowledge guided the research design as expert taekwondo coaches are presumably abreast of rule fluctuations and resultant modifications in kicking techniques.[18] This approach will enrich research designs in future investigations and aid performance programmes.

The variables shaping the cut (i.e., the knee angle and the IPD at the cut) appear to be critical in competition settings as an indication of the preparatory movement to the genuine attack (the roundhouse kick). The factors around preparatory movements deserve further exploration because of the present results and intriguing past research. Perturbations in the system of a squash game will sometimes open up temporary periods of instability that may be capitalised on.[185] These imbalances may result from shots that disturb the rally and usually precede rally outcomes (winner, error, or let).[185] Similarly, Czajkowski (2009)[186] suggested that shifting the rhythm of one's direct and indirect actions may contribute to manipulating the opponent's game plan in fencing. Combat sports can be evaluated at both the local and global level.[187] The local level include the individual opponents' goals of scoring without being scored upon and the discreet movements that arise from these. At the global level, the rhythm of the co-adaptations of the combatants constrained their behaviours. In taekwondo, disturbances to this rhythm usually take the form of steps, feints, along with the aforementioned cutting kick, and should be integrated in offence training.

Future research can focus on the critical variables identified in this study or verify the other candidate variables identified by expert coaches and athletes. To better distinguish expertise that may ultimately produce a greater number of significant results, the criterion for the selection of participants may be changed to the success in recent competitions (i.e., medallists and non-medallists).[21, 81] Doing so will ensure that medallists will most likely be more attuned to the affordance of the PSS. As in the present study, preliminary tests on scoring effectiveness on the PSS may also be a useful differentiation criterion. The representative research design used in this study may be improved on by making the target's rhythm more random, as well as allowing the option of kicking the head. Offering a choice of targets coincides with the present study's expert coaches' contention that the knee angle at the cut may give the attacker options depending on the opponent's reaction to the preparatory movement. Athletes may display different coordination patterns if the alternative to kick the head is present. It would be an interesting improvement to experimental design in the future if head safety could be ensured. Adding this randomness will create a more representative task that may discern expertise better for future investigations. Another factor that could be modified might be the height of the opponent. Past studies have matched the target to the level of the kicker's torso (e.g., Kinoshita & Fujii, 2014).[98] A great disparity in height might cause the kicker to modify their coordination pattern enough to affect scoring success and should be controlled for in following investigations. In future investigations, more participants and more scoring kicks may be added for a more robust analysis. Correlations between the IPD as the control parameter and candidate order parameters may also be explored in the future. For example, support foot balance was mentioned prominently by experts in Chapter 3 but may have been inadequately observed here. A more appropriate measure may be an order parameter that correlates with the IPD. Other scoring combinations may be investigated, focusing on the role of preparatory movements as research is lacking in this area. Finally, the coaching-biomechanics interface in this study may be adapted to investigate coordination in other skills. Despite the equivocal results due to the lack of power in the current study, some of the observed variables appear to be effective in detecting differences in representativeness. In combination with the study described in Chapter 3, this study presents a framework in which expert and researcher knowledge are integrated to produce variables that are useful to both.

4.6 Bridging Statement

The study presented in Chapter 4 provided some support to the utility of the coaching-biomechanics interface while affirming three critical variables of the taekwondo roundhouse. The representative research design contributed to the generalisability of the results to performance contexts. One potential follow-up to this study is to observe changes to these critical variables in an intervention design.

CHAPTER 5

USING ECOLOGICAL DYNAMICS TO EXPLORE EXPERTISE-APPROPRIATE LEARNING DESIGN FOR THE TAEKWONDO ROUNDHOUSE KICK. A CASE-SERIES.

This chapter comprises the following manuscript:
Bercades, L. T., Oldham, A., Lorimer, A., Millar, S.-K., & Sheerin, K. (2022). *Using ecological dynamics to explore expertise-appropriate learning design for the taekwondo roundhouse kick. A case-series*.

5.1 Preface

Chapter 5 presents Study 3 of this thesis wherein a representative learning design based on ecological dynamics was applied to detect changes in the critical variables confirmed from the study presented in Chapter 4. Study 3 is presented as a case-series to show the usefulness of the present learning design in progressing movement coordination towards expert behaviour as identified in the previous study. The variables from the first study are referenced here as well. The series of studies forms a potential framework for applying the coaching-biomechanics interface.

5.2 Introduction

Ecological dynamics is an approach to studying human behaviour that integrates the concepts of ecological psychology and dynamical systems theory.[107] This approach to learning views the acquisition of skill as a result of interactions between learners and the environment.[1] During these interactions, each learner perceives the environment and then scales their movement coordination based on their individual characteristics and capabilities.[109] For example, in combat sports that involve striking techniques, one important feature that influences movement is the interpersonal distance (IPD) of the fighter-fighter dyad.[90, 108, 112] The IPD regulates the actions and intentions of athletes relative to perception of target 'strikability'.[12, 112] As learning proceeds, athletes produce changes in the environment (e.g., fluctuations in inter-individual interactions) that provide further cues for learning progression as well as novel affordances.[110] Skilled athletes are able to achieve consistent performances in the changing environments of competitive sport, an ability termed 'dexterity'.[43] Ecological dynamics attempts to describe how athletes learn to exploit available sources of information to control performance, and which perceptual cues aid learning.[1]

Within dynamical systems theory, coordinated behaviour emerges in dynamic contexts as a result of the athlete's intentions and self-organises within the restrictions of the constraints of that action.[114, 115] In striking combat sports, specifying information on the target's strikability controls behaviour within a fight.[90] Strikability incorporates the reachability constraint and the constraint related to the intended impact energy to the target (i.e., sufficient energy to score a point).[12, 90] Coordination is achieved because human movement systems have degeneracy, in which structurally different components of the biological systems are able to self-organise to achieve similar task outcomes.[2, 12, 90] With increasing levels of expertise, athletes are able to focus on the key information sources in a variety of performance contexts to exploit system degeneracy.[2] For example, in a study of elite fencers, the opponent's approach velocity has been found to influence the perceiver's perception of affordances more than the opponent's stature.[111] The potential locations of attack is another important source of information, as demonstrated in a study that compared the height of gaze fixation between elite kung fu and taekwondo athletes.[188] The kung fu athletes fixed their gaze higher on their opponent's body compared to the taekwondo athletes, before and during the first attack. The fighting style constrained the potential locations of attack, as the kung fu athletes attack with their arms and legs, while taekwondo athletes predominantly use their legs.

Ecological dynamics characterises expertise in a sporting movement by greater functional movement variability during a task, with more stable task outcomes.[43, 83, 93] Movement variability is considered functional as it allows for more flexibility for movement adaptation and error correction during skill execution and learning progression.[9, 83] Movement variability may reveal the nature of system organisation and simultaneously, it will give practitioners an indication whether a skill is already well-learned.[83] Variability does also occur randomly (termed stochastic), in which each possible outcome is equally likely to happen.[92] As there are difficulties with the concepts and quantification of randomness and stochasticity,[92] the current research will focus on movement variability. The coefficient of variation (CV) was found to approximately capture this phenomenon in the past,[96] and was used in the present study to indicate the variability of coordination.

A continuing challenge among coaches is to recognise and manipulate key constraints in order to create purposeful behaviours during practice sessions in order to maximise training.[2] Constraints regulate the interacting parts within the complex system of motor skill acquisition.[3] Organismic constraints are the unique characteristics of individual learners, which include physical, psychological, and emotional features. Environmental constraints refer to the qualities of the learning context, which include its physical attributes (e.g., light, temperature, noise, etc.). Task constraints are more specific to particular performance settings and incorporate the rules, equipment, boundary markings, and most importantly, the sources of information available to the athletes for them to regulate their actions (i.e., other team members, opponents, etc.).[3, 117] Ideally, coaches need to design learning sessions integrating these constraints to better represent the performance environment to help the learner produce more functional movement solutions.[4] Additionally, learning designs should be appropriate to the skill level of the learner, and should be adjusted as the learner progresses, enabling them to develop specific information-movement couplings that they can exploit to support their actions.[3] The mutual interdependence of perception and movement forms the foundation of representative learning design.

Brunswik's work on representative design[6] underpinned Pinder et al.'s[5] representative learning design (RLD) framework. The term 'represent' was originally defined as the organisation of constraints in an experimental design to embody the behavioural setting to which the results are meant to apply.[5, 6] The process requires sampling constraints from specific performance environments that preserve perceptual cues in order to regulate the athlete's actions.[6] For example, the presence of an opponent while learning a sports skill has been shown to affect movement coordination.[94, 124] In combat sports, athletes use information from the opponent's movements to predict their intended actions before they initiate their own movement. Skilled athletes may even manipulate their opponents by creating affordances to draw out the initial movements. This example exemplifies another foundation of RLD, which is Gibson's insights on perception-action coupling.[7] Skilled athletes depend on the accurate and efficient relationship between perceptual and motor skills, focusing on the relevant performance environmental cues, and producing the appropriate movement solutions [5]. Therefore, preserving these couplings in learning environments may produce better skill transfer to competition contexts. Pinder et al.[5] provided principles in creating an RLD. Practitioners should create dynamic, rather than static, practice tasks that sample information sources from performance contexts. Examples in soccer[170] and boxing[45] demonstrated the usefulness of dynamic tasks to skill learning and permanence. In RLD, learners should also be able to closely connect the indicators of success between the learning context and the performance environment.[5] In taekwondo, sparring in practice using the competition Protector Scoring System (PSS) will directly signify success in both contexts. Additionally, dyad training is beneficial as it increases the learner's motivation by adding the element of competition.[125] Attentional load for both learners in the dyad is also high, facilitating more focus on the task.[126]

Combat sports such as judo, taekwondo, and boxing offer a rich context for studying dynamic skills as they involve a complete dyad that preserves key information-movement couplings.[12] These are also Olympic sports that reflect high levels of expertise. These sports are also deeply grounded in instructional or traditional models of learning;[11, 189] therefore presenting a valuable opportunity to explore modern pedagogical methods. Competitive combat sports are based mostly on traditional martial arts, which seek to understand oneself by training the body and mind by way of meditation, forms, prearranged and free sparring, and breaking.[133] Forms (*hyung* in Korean and *kata* in Japanese) are choreographed sequences of defensive and offensive techniques against imaginary opponents. Constant repetition of forms has been considered to support basic technique learning and helps develop control, confidence, balance, and coordination.[133] When an athlete has been officially judged skilful enough to advance they then learn new forms to acquire new techniques.[133, 189] The traditional approach is appropriate for preparation for forms competition, and may be useful for novices early in the coordination stage of learning to stabilise skills.[3] For example, a study that examined the muscle activation during the performance of a no-target karate roundhouse revealed greater activation of the antagonists that may help to control coordination.[182] But as different constraints are applied in sparring contexts, a more representative approach might be better suited to prepare the learner to adapt to changing information-movement couplings and rule changes.[2]

Combat sports provide a useful platform for exploring theory-practice links due to their compact dyadic nature. Specific research has been carried out on judo[11, 44] and boxing,[112, 190] but a gap exists in the knowledge with respect to foot striking skills. Most studies on learning and mastering the kick focus on soccer.[191, 192] Only a handful of research studies have been found on the general instruction of taekwondo[127, 193] and kicking in particular.[46] Moreover, taekwondo presents a constrained target (the PSS) not present in most combat sports. While insights from expert coaches may benefit instruction and learning, no research applying expert knowledge was found on taekwondo. Applying concepts of ecological dynamics as well as expert knowledge to learning kicking skills will complement the traditional approach currently used.

Taekwondo is a traditional Korean martial art that features striking with the hands and feet. Taekwondo has gained popularity as a combat sport because of its exposure in the Olympic Games.[17] Competition rules are continuously revised in response to audience feedback, judging transparency issues, and safety concerns necessitating frequent adjustments of techniques and tactics.[18, 102, 140] The taekwondo roundhouse or turning kick to the torso (*dollyeo-chagi*) is the most common attacking technique in taekwondo competition[20] and its kinematic properties have been studied rigorously. However, research on the acquisition of kicking skill is uncommon. Only one study in English was found on learning roundhouse coordination. Kim[46] found changes in segmental velocity and kicking leg pattern in novice participants learning the taekwondo roundhouse kick after a five-week practice period. The participants were allowed to self-organise their technique to find the appropriate solution to the task constraints. Not only did they increase their foot velocity, but they also improved their accuracy over time, indicating that the learners may have already established a basic kicking pattern prior to practice that allowed them to improve performance.[46] From these encouraging results, opportunities are plentiful to study the effects of RLD by manipulating practice constraints on coordination patterns and performance outcomes of taekwondo techniques, especially those used in dynamic competitive contexts.

This study's primary aim is to investigate the effects of a six-week representative learning design on the critical coordination variables and effectiveness of the taekwondo roundhouse combination. In addition to time related differences, post-intervention variability changes in the critical variables to expert coordination patterns were also compared. Following expertise-related differences in the past,[83, 93] it was expected that variability would increase with practice and as the representativeness of the task increased. This study also seeks to continue the work from the previous two studies (see Chapters 3 and 4) by using the coach-identified and researcher-translated variables and comparing practice-related changes to variability patterns to those from Chapter 4.

5.3 Methods

5.3.1 Overview of the study

A case-series design was used in which multiple single-subjects were observed, where the dependent variables were measured at two timepoints: pre-intervention and post-intervention.[194] The intervention stage spanned six weeks, during which the participants were allowed to participate in their regular training, in addition to the study's learning design. The participants' scoring averages were collated before, immediately after the intervention, and after a two-week retention phase. Scoring averages were calculated by dividing the number of scoring kicks by the total number of attempts.

5.3.2 Participants

Four intermediate taekwondo athletes participated in this study. Due to the technical nature of the kicking combination being observed, and the need to ensure the safety of all participants, only athletes with at least intermediate competition experience were included. The participants were selected from the intermediate participants from Chapter 4, who were re-classified by their scoring averages in the

Dynamic Target condition. Three participants trained in the same club, and their coaches judged them to have intermediate skill. The fourth participant had considerable practice experience but appraised themselves to have intermediate skill in the particular kicking combination investigated in this study. The participants are considered to be within the control stage of learning where they have relatively stable patterns of movement coordination.[195] The three athletes belonging to the same taekwondo club went through the intervention at the same time and trained by the lead author. One additional participant was trained along with two others (who did not have sufficient data for analysis) by the lead author. See Table 5.1 for participant characteristics.

Table 5.1: ***Participants' Characteristics***

Participant	Age (years)	Height (m)	Weight (kg)	Leg length (cm)	Years of practice	Years of competition
1	40	1.65	65.3	92.0	5	4
2	11	1.32	29.5	56.0	5	4
3	24	1.80	71.1	92.2	10	2
4	13	1.69	52.4	83.0	2	1

5.3.3 Procedure

After a 10-minute warm-up, including time to practice the combination on the PSS (Gen1, Daedo, Barcelona, Spain), each fighter performed a cut-roundhouse kicking combination (see Figure 1). The combination began with the 'cutting kick' or 'cut', which is a preparatory action involving a hopping forward with the rear (supporting) leg, while doing a push-like kick, involving the simultaneous hip and knee extension. This was followed by the roundhouse kick (Figure 1c), which is characterized as a throw-like movement defined by hip flexion followed by knee extension.[77]

Participants performed as many kicks as necessary to achieve five scoring kicks under the following conditions in a randomised order: no target (NT), static target (ST), and dynamic target (DT) (see Table 5.2). For the ST and DT conditions, the fighters kicked an opponent wearing the PSS. The three conditions are commonly used in taekwondo practice, and analysis of coordination differences may provide valuable insight on the usefulness of these conditions for learning. The PSS was calibrated based on each participant's weight division, gender, and age/competition bracket. Only the kicks that activated the PSS were analysed. Each participant was allowed 10-30 seconds rest between trials and 30-60 seconds between kicking conditions.

Table 5.2: ***Kicking Conditions***

Kicking condition	Details
No target (NT)	The participants were instructed to perform the combination at the same speed and intensity they would in competition.

Static target (ST)	The target consisted of an opponent wearing the PSS in a stationary ready stance.
Dynamic target (DT)	The PSS-armoured opponent slid backwards away from the participant to simulate an indirect attack by the participant (i.e., a preparatory movement [the cut] and the attack [the roundhouse]).

Kinematic data were measured using a 9-camera three-dimensional (3D) motion analysis system (Vicon, Oxford, UK), sampling at 200 Hz. Retroreflective markers (10 mm) were attached to specific anatomical landmarks. Clusters of four markers, on thermo-moulded plastic shells, were attached to the thigh and shank. Pelvis and torso markers were also affixed on the opponent. Following a standing static calibration, the femoral condyle and malleoli markers were removed. For dynamic calibration of the hip joint, the participants performed a combination of flexion, abduction, adduction, and extension movements on each leg. Three shallow squats were performed to calibrate for the knee joint centre.[176] Anatomical co-ordinate systems were defined according to specifications reported by Besier et al. (2003).[177]

5.3.4 Data Processing and Interpretation

Raw kinematic data was imported into Visual3D (C-Motion Inc, MD, USA) and applied to a custom model with an additional pelvis and torso for the target for the static and dynamic trials. Standard Visual 3D inverse kinematic constraints were applied to the hip, knee, ankle, torso, shoulder and elbow joints. Marker signals were filtered with a single bidirectional 15Hz low pass Butterworth filter. Velocity of the foot segment, hip angle, knee angle and pelvis displacement were extracted from the modelled data. Data were discarded when insufficient marker data were present to make reconstruction possible.

The roundhouse kick technique was subdivided into seven events described in Chapter 4. The observed variables were translated from previously determined expert knowledge (Chapter 3) and analysed with respect to differences between expertise levels (Chapter 4) (see Table 4.3). Expert coaches identified six main themes that were translated into five observable variables. Three variables were selected from Chapter 4 for further analysis based on two criteria: main effect and interaction; and marginal significance/moderate effect sizes and measures of partial association. These variables may form the basis for an expert model that might reflect change in response to the applied pedagogy in the current study. These three critical variables are: Front knee angle at the cut (KAC), front knee angle at the kick (KAK), and interpersonal distance at the cut (IPDC).

5.3.5 Learning intervention

The present learning intervention aimed to improve the effectiveness of the cut-roundhouse combination by influencing the critical variables previously identified by expert coaches in Chapter 3. Specifically, the tasks sought to improve the participants' control over the effective scaled distance to the target (i.e., the IPD at which they could score a point).[45] Expert coaches previously described the optimal IPD as the proper distance so that the kick is not short (i.e., not fully extended). The intervention also intended to develop kicking coordination to ensure sufficient impact energy to score on the PSS.

The coaches described this as kick speed, snap, or flick. Supporting-leg stability was another factor to be improved. Coaches mentioned its importance in the delivery and recovery of the kick, particularly in preparation for a follow-up kick. The height of the cutting kick was also a common factor mentioned by all the coaches and was targeted by the intervention.

The learning intervention was administered over 12 sessions, twice weekly for six weeks. The lead author has both competitive and coaching experience in taekwondo and directed all the training sessions. Each learning task was designed to quickly advance to greater degrees of representativeness by manipulating task and environmental constraints. As the tasks progressed to sparring, intentional constraints were directed through role-playing (i.e., attacker and defender) that encouraged emergent solutions to variable provocations to action.[1] Sparring was also simplified to focus on the kicking skill being developed. Progression through the learning design was individualised to each participant. Participants were allowed to stay at a particular task, regress, or skip task progressions according to their ability as determined by the club's two coaches and the first author.[3, 4] The intervention was different from the traditional manner in which skills are learned and assessed in a large group.[127] Instructional feedback was limited to cues on movement effects (i.e., creating more sound on impact on the target) to allow the participants to explore individual solutions to the movement quandary.[4] Prior to the use of the PSS, the sound on the *hogul* (armour) was an indicator for scoring a point and was used here to indicate kicking success.[18] Repetitions of the learning tasks were kept to 10 to prevent neuromuscular fatigue and ensure high quality effort.[193, 196]

Videos were taken of each learner performing the tasks in each session and footage was taken of the middle to final repetitions of each drill of each session to ensure that skill has stabilised.[3, 83] The coaches viewed the videos at the end of each session and agreed on the next progression. The coaches had the option of either progressing, remaining, or regressing the athlete at their present task to maximise learner attunement.

There were three learning tasks. Each one followed a progression of increasing degrees of representativeness. The task constraints that were manipulated were movement of the target (from static to dynamic), distance of the target, target direction, pattern of target movement (from a set forward-backward to random pattern), rhythm of target appearance (from set to random), and target type (from paddle to armoured partner). The environmental constraint controlled was the space allowed to perform the task. The first author presented the target to all the participants in all the sessions. Apart from instructing the participants of the kicking combination they would execute, and the task outcome (i.e., an audible sound on the paddle or hogul), no additional augmented feedback was provided.

During the first learning task, referred to as 'Distance Discovery', participants performed the kicking combination on the paddle held by the researcher. The combination was performed 10 times on each leg with a brief rest (3-5 seconds) after each repetition. The second task, referred to as 'Single-leg Balance', was similar to the previous task, but the participants performed the combination in an initial cutting position (i.e., standing on one foot with the knee up). During the third task, referred to as 'Cut and Recovery', a hurdle was set up in front of a wall with room in between for the participant slide forward and backward naturally. The hurdle formed a task constraint to limit the kicker's knee height, while the wall constrained the participant's posture. In Chapter 3, coaches emphasised a more upright posture for more efficient kicking coordination. All progressions are described in detail in Appendix C.

Sparring was scaled down to the cut-kick combination. The degree of representativeness was manipulated by controlling the area the defender moved in and the roles within the attacker-defender dyad. As with the paddle, the task outcome was to generate an audible sound on the hogul to indicate a point. The situational sparring progressions are detailed in Appendix C.

5.3.6 Statistical analysis

Coefficients of Variation (CV) were calculated by dividing the standard deviation (SD) by the mean of the variable of interest for primary analysis.[96] The CV measures the variability of a series of data independently of the unit of measurement used,[178] making it an appropriate omnibus test for the different variables observed in this study. Using the CV allows the ratio between the SD and the mean to be constant while allowing both to vary.[179] Therefore, SD was used in this study as a subsidiary confirmatory test because it was a more informative index of coupling. ANOVAs were performed on the scores and variables: A one-way ANOVA with score as the dependent variable (ST and DT). A 2 (Time) x 3 (Target) repeated measures ANOVA for KAC and KAK with both CV and SD as dependent variables. A 2 (Time) x 2 (Target) repeated measures ANOVA for IPDC with CV and SD as dependent variables. Omnibus tests with follow-up testing were selected to analyse the multiple variables. This approach is relatively parsimonious and avoids examining arbitrary differences (Type 1 errors). The shortcoming of the approach is the lack of applicable statistical power in the study (vulnerable to Type 2 error). For each participant, pre-post differences were computed for CV and SD and compared by visual inspection to coordination patterns for each variable as described previously in Chapter 4.

5.4 Results

The participants' scoring averages for ST and DT conditions are presented in Table 5.3. There were no significant time-related results for the dependent variables and scoring averages for each of the participants. Consequently, a difference analysis was pursued at the intra-individual level to determine if there was any evidence of learner's progression toward the expected expert pattern or the patterns of the same variables from Chapter 4.

Table 5.3: ***Participants' Scoring Averages***

Participant	ST scoring average			DT scoring average		
	Pre-intervention	Post-intervention	Retention	Pre-intervention	Post-intervention	Retention
1	0.64	0.18	0.63	0.71	0.19	0.42
2	0.55	0.63	0.56	0.25	0.28	0.50
3	0.60	0.14	0.33	0.50	0.26	0.20
4	0.42	0.63	0.63	0.28	1.00	0.50

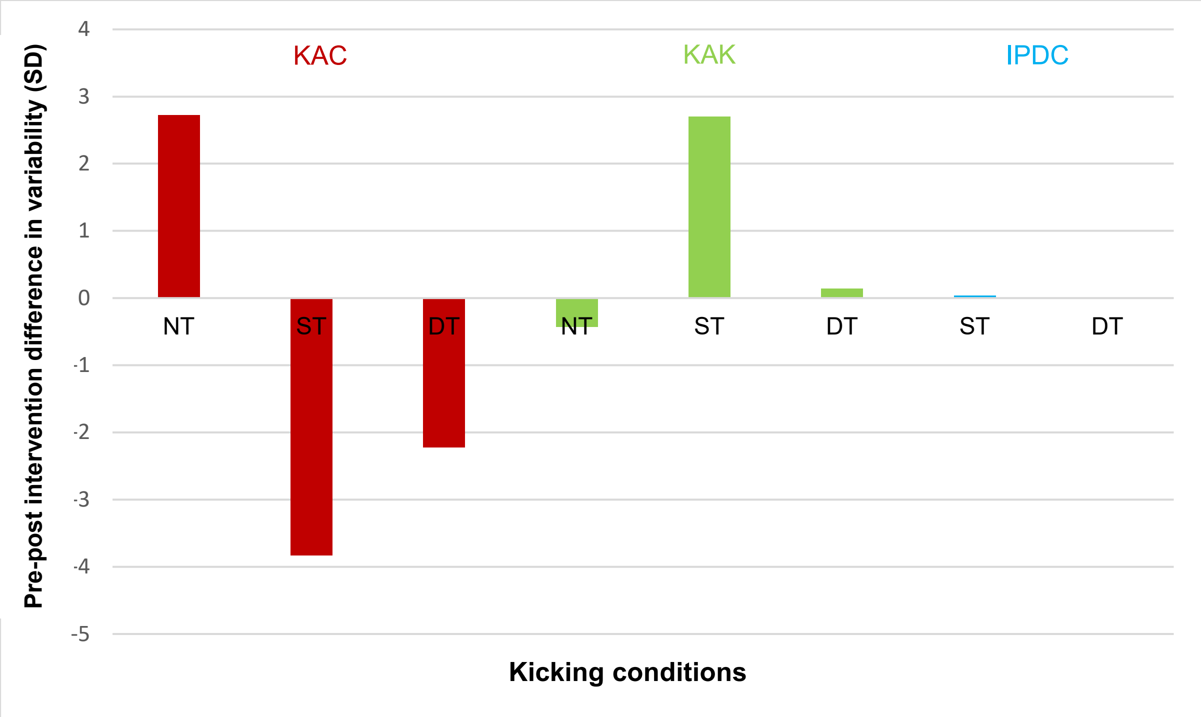
Note: ST – Static target; DT – dynamic target; no target to score for the NT condition.

The pre- and post-test differences in variability (as SDs) are presented for each participant in each of the observed variables: KAC, KAK, and IPDC. Data for KAC and KAK are presented for the three kicking conditions of increasing representativeness: No target (NT), Static target (ST), and Dynamic target (DT). Data for IPDC are presented for ST and DT only. Following expertise-related differences in the past,[83, 93] it was expected that variability would increase with practice and as the representativeness of the task increased. However, the patterns of these variables were different from those from past studies as demonstrated in Chapter 4. So, to provide continuation from the first study to the present study, comparisons will be made to patterns found in the previous study (Study 2). No significant differences were found in all three variables over time. Results are presented below for each participant.

5.4.1 Participant 1

Time-related variability changes (SDs) for each variable are presented in Figure 5.1 for the different kicking conditions for Participant 1. The direction of change in variability (i.e., increase or decrease) was compared to the model of coordination previously described in Chapter 4. The pattern of variability of KAC changed as the degree of representativeness from NT to ST to DT. There was a reduction in variability between the NT and the targeted conditions, indicating a similarity with the Study 2 model. However, variability in the DT is less than that in ST condition, which deviated from the Study 2 pattern of increasing variability in the DT condition. There was an increase in KAK variability in both targeted conditions compared to the NT condition, which differed from the coordination in Study 2. There was a reduction in IPDC variability as the degree of representativeness increased, which is similar to the Study 2 pattern.

With respect to their whole coordination system, Participant 1 did not display the same patterns as the experts from Study 2 after the intervention. Changes in KAC variability approached Study 2 coordination as variability decreased from the NT to ST conditions but deviated as representativeness increased in the DT condition.

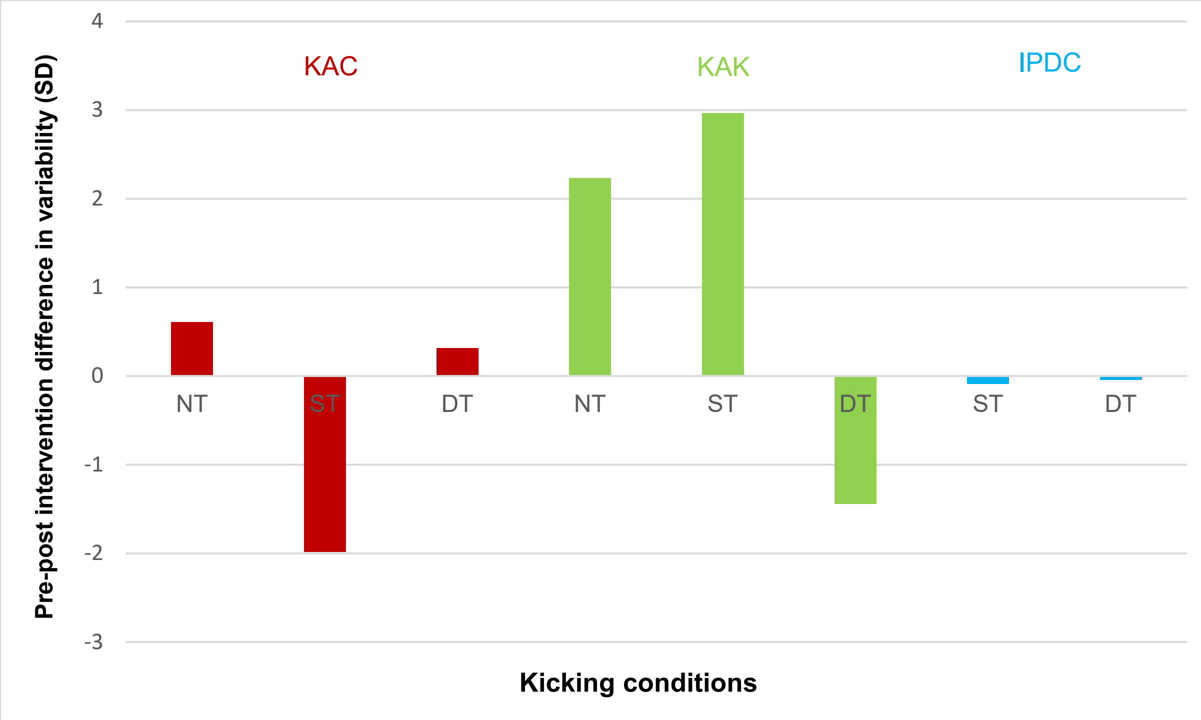


Note: KAC – Knee angle at cut; KAK – Knee angle at kick; IPDC – Interpersonal distance at cut; NT - No target; ST – Static target; DT – Dynamic target

Figure 5.1: ***Post-test Differences in Critical Variable Variability Across Kicking Conditions for Participant 1***

5.4.2 Participant 2

Figure 5.2 displays Participant 2's time-related coordination pattern as described in changes in the variability of KAC, KAK, and IPDC. With the decrease in KAC variability in the ST condition, Participant 2 adopted similar behaviour as the experts from Study 2. But a subsequent increase in variability in the DT condition reversed that pattern. Regarding KAK variability, there was an unclear resemblance with the Study 2 pattern with the initial increase in variability in the ST condition to more similarity in the DT condition. Post-intervention, Participant 2 demonstrated a difference to the Study 2 coordination in IPDC as variability increased from ST to DT.

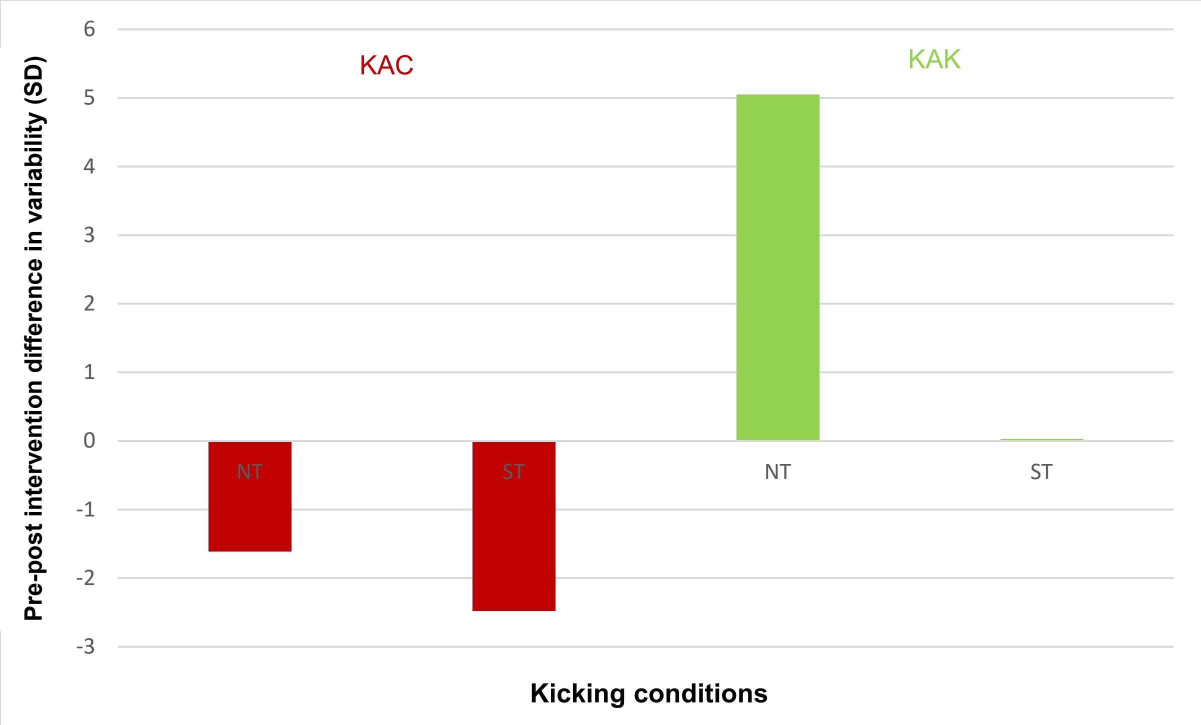


Note: KAC – Knee angle at cut; KAK – Knee angle at kick; IPDC – Interpersonal distance at cut; NT - No target; ST – Static target; DT – Dynamic target

Figure 5.2: ***Post-test Differences in Critical Variable Variability Across Kicking Conditions for Participant 2***

5.4.3 Participant 3

Figure 5.3 shows variability for the NT and ST conditions only as Participant 3 had insufficient data for the DT condition, as well as no data for IPDC. The KAC variability decreased from NT to ST, showing a resemblance to the pattern from Study 2. The Study 2 pattern of decreasing KAK variability from NT to ST is also displayed.

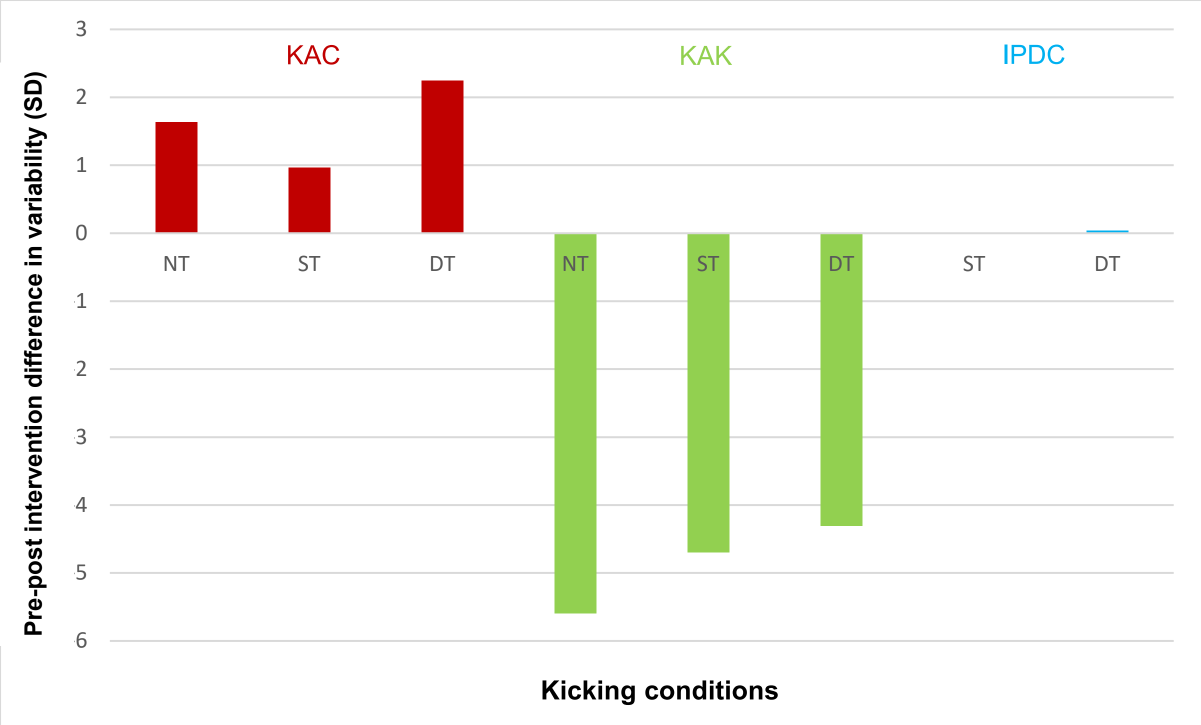


Note: KAC – Knee angle at cut; KAK – Knee angle at kick; IPDC – Interpersonal distance at cut; NT - No target; ST – Static target; DT – Dynamic target

Figure 5.3: ***Post-test Differences in Critical Variable Variability Across Kicking Conditions for Participant 3***

5.4.4 Participant 4

Figure 5.4 describes time-related kicking coordination changes as KAC, KAK and IPDC variability over different levels of representativeness for Participant 4. KAC resembled the Study 2 behaviour from the NT to ST conditions as variability decreased but deviated from it in the DT condition as variability increased. Participant 4 deviated from Study 2 coordination in KAK as variability increased with greater representativeness. Difference from the Study 2 model was apparent in IPDC as variability increased from ST to DT conditions.



Note: KAC – Knee angle at cut; KAK – Knee angle at kick; IPDC – Interpersonal distance at cut; NT - No target; ST – Static target; DT – Dynamic target

Figure 5.4: ***Post-test Differences in Critical Variable Variability Across Kicking Conditions for Participant 4***

For KAC, only Participant 3 demonstrated the pattern from Study 2 of decreased variability with increasing representativeness, specifically from the NT to the ST conditions (see Figure 5.3). Participants 1, 2 and 4 (see Figures 5.1, 5.2 and 5.4, respectively) followed the Study 2 model as variability decreased in the ST condition but stopped in the DT condition. For KAK, only Participant 3 appeared to move towards the Study 2 model as variability decreased from the NT and ST conditions (see Figure 5.3). Participants 1 and 2 (see Figures 5.1 and 5.2, respectively) had unclear resemblance with the Study 2 pattern as variability increased in the ST condition from the NT before increasing in the DT. Participant 4 (Figure 5.4) followed a trend of increasing variability with the degree of representativeness, which is the inverse of the Study 2 pattern. For IPDC, Participant 1 (see Figure 5.1) approached the Study 2 pattern of reduced variability in the DT condition compared to the ST condition. Participant 2 and 4 (see Figures 5.2 and 5.4, respectively) reflected the opposite pattern of increasing variability between the ST and DT conditions.

None of the participants moved towards the Study 2 model in all three observed variables post-intervention. Participant 1 resembled the Study 2 pattern in KAC but only during the transition from NT to ST, and also demonstrated IPDC pattern similar to Study 2. For Participant 2, both KAC and KAK had unclear patterns over the degrees of representativeness. While Participant 3's data were incomplete, changes in KAC and KAK variability between the NT and ST conditions indicate approximation of the Study 2 model. With Participant 4, the Study 2 pattern was not clearly seen for KAC, and KAK yielded non-expert coordination.

5.5 Discussion

This study's primary aim was to investigate the effects of a six-week representative learning intervention on the critical coordination variables and effectiveness of a taekwondo roundhouse combination. Comparisons were made to coordination patterns from Chapter 4 as variability changes in KAC, KAK, and IPDC between levels of representativeness (i.e., NT, ST, and DT conditions). Following pattern changes in Chapter 4, we expected variability of the KAC and KAK to reduce as the representativeness of the task increased as it 'settled down' to a consistent, functional level.[83] For the IPDC, we expected less variability in the DT condition. No significant time-related differences were found. None of the participants displayed the expected expert patterns in all three variables (KAC, KAK and IPDC). Taken together, the limited implementation of the present learning intervention appeared to result in some expected coordination patterns in IPDC and several unclear changes in KAC and KAK. However, the changes in coordination did not produce clear immediate or lingering post-intervention scoring improvements.

The front knee angle at the cut and kick were previously recognised by expert coaches in Chapter 3 as critical variables of the cut-roundhouse combination. Investigations of the KAC showed reduced variability when a target is present, while KAK variability increased with representativeness. In contrast to studies in the past that considered variability as 'noise', ecological models view expertise as characterised by stable task outcomes associated with greater movement variability.[83] While there is a notion that greater control over the degrees of freedom of a movement pattern represents greater skill, there seems to be a greater collaboration between the stability of a skill to achieve consistent task outcomes, and the flexibility for error correction and adaptation during the progression of learning.[83] Fluctuations in variability may suggest a state of metastability of the target-kick coupling and could signal a transition in their developmental stage.[3] Metastability is a property that enables many coexisting functional solutions having different levels of novelty for the same set of constraints.[190] As a movement is learned, movement variability 'settles down' to a consistent, functional level.[83] In this study, it seems possible that due to a change in constraints, learners are forced to shift from a stable (well-practised state) to another state which is less practised. In this context, the lower variability of the knee angle at the cut and the kick in the targeted conditions may point to the participants' greater control over the coordination pattern. Additionally, the reduction in variability is an indicator of task-specific visual regulation previously seen in high jumpers of varying expertise.[184] However, while the use of visual regulation was evident in all levels of expertise, accuracy at the high jump take-off seem to improve with specific task training.[184] Therefore, representative taekwondo training with the presence of dynamic targets is recommended to improve the coupling between visual regulation and coordination.

The metastability of the target-kick coupling may help clarify the ambiguous immediate and lasting scoring performance. The brief learning intervention duration may have influenced the metastability by capturing the fluctuations in variability between testing sessions. While some research in combat sports had shorter durations resulting in significant differences between pre-, post-intervention and retention performances,[11, 46] measurements of performance differed from the present study. Gomes et al.,[11] for instance, used expert instructors to assess the global performance of a judo throw. While Kim[46] examined segmental velocity and segmental lag to detect coordination changes in the taekwondo roundhouse. In contrast, the representative research design used in this study and the observed critical variables may have provided a more ecologically valid environment to detect significant changes. Additionally, as the present participants' progression through the learning intervention was regulated by their coaches, they were not able to advance to the situational sparring tasks that could have contributed more to coordination changes (see Appendix C). As such, the brief intervention period may have captured the participants' coordination metastability between developmental stages that also reflected their unclear performance patterns. The benefits of RLD may take longer to emerge and a longer intervention is needed for the present participants. Future research may take note at which level of representativeness each learner progresses to at the end of the intervention, or the length of intervention period at which each individual progresses to the highest level of representativeness for each task.

No published research was found on the IPD during preparatory actions (i.e., the cut) and the effects of practice. However, the reduced IPDC variability as a response to the moving target found in the Study 2 pattern (see Chapter 4) appeared to have been shown in one participant post-intervention, although no significant differences were found. As with the knee angles, the influence of changes in IPDC variability did not result in any discernible performance changes. However, exploration of affordances by means of preparatory actions, as well as the factors surrounding them, provide rich opportunities for future research. Meanwhile, the present results point towards the usefulness of observing the IPDC in research involving striking techniques in dyads. Practice with more representative tasks, such as those with a moving target, seems to be indicated for technical improvement. Simplified scenario tasks wherein both combatants may attack (i.e., a "golden point" set-up in which the first person to score a point wins) will not only hone learners' technique to the affordance of an authentic antagonist, but also help them develop effective preparatory actions to create those affordances.

The current study provided some guidance on measuring striking performance in taekwondo research. It appears valuable to investigate multiple indicators of coordination as well as their relationships with each other. A nested task such as the cut-kick combination has co-dependent coordinative couplings in which changes in one variable will have to be accommodated elsewhere. Measuring movement variability seems to provide greater information on how learners self-organise systems to adapt to changing constraints. The present representative research design presented a novel way to identify coordinative changes with practice. In future investigations, qualitative analysis of videos of the progress of the participants will complement the quantitative data. Data on the participants' thoughts and feelings may also uncover psychological influences on coordination changes over time. Additionally, video analysis used in coaching practice may enhance learning. The study's learning design allowed each participant to progress, regress or remain at their present level of task representativeness, which could complement traditional group training scenarios. The constraints identified and how they were manipulated could easily be adopted to coaching practice. This study is not without limitations. Specifically, future investigations can use a greater number of participants and a control group to allow for the enhanced interpretation of changes. A more definitive criterion for participant selection (i.e., pre-test scoring average) may better determine the learning design's effectiveness. Lastly, the intervention duration could be customised to each individual's level of progression in future research. Taken together with the research processes previously described in Chapter 3 and 4, the current study provides a model of discovering new knowledge using the 'coaching-biomechanics interface'[35] for forthcoming investigations.

CHAPTER 6

SUMMARY, LIMITATIONS, PRACTICAL IMPLICATIONS AND CONCLUSION

The overall aim of the thesis was to draw on expert knowledge and integrate it to concepts of ecological dynamics to improve the performance of the taekwondo roundhouse kick. To this end, three studies were undertaken. The first study determined the critical variables of the roundhouse kick by collecting the expert knowledge in a representative approach and transforming the data into observable biomechanical variables. The candidate critical variables from the first study (Chapter 3) were observed in the following study (Chapter 4) by investigating expertise-related differences using a representative research design to verify their usefulness in coaching and research. Finally, the study presented in Chapter 5 sought investigate the effects of a six-week representative learning design on the critical variables and effectiveness of the taekwondo roundhouse combination. The following summarises the findings of each study, presents the limitations, offers practical implications, and proposes directions for future research.

6.1 Study 1 (Chapter 3)

Study 1 concentrated on the critical variables affecting the execution of the cut-roundhouse combination commonly used in competition. The coaches considered the knee height during the cut important for both defence (to guard against body attacks) and offence (for more kick choices). Unilateral balance was associated with the cut and the recovery by the coaches. The coordination of the roundhouse kick was discussed by the coaches in a holistic manner, including the supporting foot, hip action, knee flexion and extension. All coaches emphasised the value of distance control while executing the roundhouse kick, and footwork was unanimously linked to this ability. Finally, the coaches related kick speed to the lag time between cutting and roundhouse kicks. Implicit in many of the coaches' comments is the need for target-movement coupling and the exploration of affordance. The author and two of his supervisors translated the expert-derived variables to biomechanical variables. Two additional coaches then assessed these biomechanical variables for usefulness and coachability.

It was challenging to find expert coaches to interview for this study. The timing of the interviews coincided with teams' preparation for the qualifying rounds for the Rio Olympics; a factor to be considered in forthcoming research. The interview process was mostly uncomplicated, although one of the coaches, whose first language was not English, would probably have been able to express himself better in his native tongue. The current study was limited to English-speaking coaches but may have been considerably enriched by interviewing world-class non-English speakers via translators. Indeed, nine of the top 10 ranked countries in the 2019 World Taekwondo Championships had official languages other than English.[197] It would be intriguing to collect and compare the knowledge of these experts.

Allowing the coaches in the current study to give verbal reports while viewing videos of performers provided a fruitful source of data, and such a method should be encouraged in the future. Perhaps showing actual match footage of successful technique delivery may encourage more reflection from the coaches. Furthermore, coaches may analyse performance more critically if showed videos of scoring and non-scoring kicks. Verbal reflection while viewing video, termed concurrent think aloud protocol, involves participants ‘thinking aloud’ while performing cognitive tasks.[147] It offers direct verbalisation of cognitive processes and is assumed to be consistent and complete. In contrast, retrospective verbal report requires the retrieval of information from previous experience that might result in unreliable information about one’s thinking process, although it may supply a more complete narrative about one’s reasoning strategies.[147] Thus, a combination of the two methods might be prescribed for subsequent research. Kimmel and Rogler[174] used a think-aloud interviewing technique that encouraged self-reflection during the performance of the observed skills and may be used in the future. A similar self-reflection method may be used by coaches in sparring practice or scenario training.

A number of the expert-identified variables had not been examined before and made comparisons to other literature difficult. As such, transforming these variables into observable biomechanical parameters proved to be challenging. However, the coaching-biomechanics interface, in which experts’ experiential knowledge and current theoretical knowledge form the basis of meaningful research questions [35], seems to be an effective way to bridge the researcher-practitioner knowledge gap[59].

Training and coaching implications for each variable are as follows:

Front knee height: While the raised knee has been suggested to be part of defence against the opponent’s attacks, recent rule changes forbid using the leg to block or impede attacks.[198] If the leg is suspended longer than three seconds, the referee may warn the competitor. As such, while a high front knee may have tactical advantages, a quick follow-up technique must be practiced along with it. Tasks of progressive difficulty may be designed to ensure the height of the knee as well as appropriate adjustments of the supporting foot and hip as suggested by the present coaches. Scenario sparring tasks may also be designed to develop the decision-making ability of the learner in throwing the applicable technique to the affordance at hand.

Unilateral balance: An eight-week progressive proprioception training program has been shown to improve dynamic postural control in taekwondo athletes.[199] The tasks advanced from double-leg to single-leg, open-eyed to closed-eyed, floor to wobble board, and 10-second to 35-second repetitions. Since the tasks were static in nature, dynamic and specific exercises may instead be incorporated in the warm-up for training sessions to better prepare for the more energetic movements of taekwondo.

Coordination/accuracy: The most representative manner to integrate coordination and accuracy is to conduct as much sparring practice with the PSS as possible. Finances may be a factor for small clubs as a Daedo TrueScore PSS set costs upwards of US$1,500. Different sizes of *hogul* must also be purchased for different athletes. Frequent rule changes that affect technology, updates on the PSS, and the specific brand favoured by the World Taekwondo Federation are issues that may also influence the acquisition of this necessary equipment. With this said, tasks leading up to those using the PSS should sufficiently prepare the learner for the task. For instance, tasks with hand-held kick pads or paddles should appropriately mimic the task constraints. Coach 1 mentioned that movement should be added into these tasks to simulate a moving target, but the orientation of how the paddles are held by the partner should also be carefully considered. A common occurrence in practice sessions is for the paddle to be held at an angle other than 90° for the roundhouse kick, which does not conform to the perpendicular sides of the human torso. In fact, this peculiarity has been carried over to some research designs. Kim et al.[77] held the paddle at a 45° so that their participants adjusted the execution of the roundhouse kicks with limited internal hip rotation. Roosen[119] and Roosen and Pain[23] oriented the paddle horizontally during the second kick of a three-roundhouse kick combination, and consequently they detected a difference in that kick's coordination compared to the other studies. The angle of the foot on impact is crucial in modern fights, as the foot protectors must land solidly on the armour to trigger the PSS, with Zhang and colleagues[200] concluding that the optimal angle for scoring is 60~90°.

Distance/footwork: Tasks for distance control and footwork may be progressively introduced to learners of different abilities. Constraints that may be manipulated include the movement of the target (static to dynamic), the direction of the movement, the distance of the target from the learner, the size and density of the target, randomness of target availability, and the level of decisional or emotional commitment. Though free sparring may be the most representative mode of practice, safety and learning may be compromised especially if both learners are insufficiently skilled.

Speed: The lag time between the preparatory movement and the attack may be practiced in isolation of dyad training (i.e., using pads and punching bags instead of sparring). A variety of preparatory movement-attack combinations must be drilled to prepare the fighter for different competitive scenarios and to prevent predictability. Increased variability in tactics may contribute to greater competition success, as it has been found that there are great similarities in tactics between genders and countries at the elite level.[201]

McGill et al.[89] suggested that the double peak pattern of muscle activity that may enhance both speed and power can be trained. One cue that the participants used was timing their yell (*kihap*) with the two pulses. The researchers interviewed a champion kickboxer, and he claimed that he imagined the double pulse while 'speeding up the tape' in between the pulses. Some martial arts masters were also said to clap their hands twice to try to coach the double pulse. The speed of muscle contraction and relaxation may also be taught by the quick release from an isometric contraction to full relaxation and full speed movement. A proper warm-up may also increase the rate of contraction and relaxation by enhancing the ability of the calcium pumps. Invoking Bruce Lee, the researchers recommended that a pulse to quickly return the foot or fist back to on-guard position might further augment the body's effective mass on impact.[89, 202] This concept supports the whip-like action favoured by our present coaches.

There is a great need for further research on the expert knowledge of taekwondo coaches as limited literature was found. Research and practice in *kyorugi* (sparring), in particular, will greatly benefit from the data presented here given the speed of rule changes for competition; there have been four amendments to the official World Taekwondo rules for competition since the 2016 Olympic Games.[198] Coaches would automatically adjust to these changes, and therefore enhance research generalisability and meaningfulness for coaches. Coaches at the highest levels of competition would quickly develop effective tactics and strategies to adapt to the changes; thus, providing valuable information and questions to sport scientists. While the rules on *poomsae* (forms) competition are not as fluid, it would still be valuable to collect experts' knowledge on this fast-developing field of taekwondo competition. Codifying and comparing experiential knowledge from experts from different combat sports and martial traditions will also be rewarding as coaches could select the most appropriate elements for application, especially in this age of mixed martial arts. Concurrently, general knowledge on combative dyadic training may be developed from these data.

A large number of the critical factors cited by the coaches did not relate directly with research, such as the variables affecting the preparatory cut kick. Overall, the effects of dyadic training on skill acquisition and physiological adaptations are currently poorly explored. Despite the number of martial traditions that use foot striking techniques, only a small number of studies in English were found on IPD and strikability, and their influence on kicking coordination and effectiveness.[13, 108] Potentially, the evolution of the cut kick as a preparatory action has been too rapid for research to keep up with it. In fact, investigations on taekwondo preparatory movements in general were scarce. Any cursory observation of taekwondo matches will reveal that scoring points does not result from isolated techniques. Hence, subsequent surveys of movements in competition should include these components put forth by the coaches. Analysis of match footage would seem to reap the most fruit for coaches, but focus should be directed more to the factors surrounding the actions setting up scoring techniques, such as modality (i.e., single, in-synch, or out of synch), lag time (i.e., rhythm changes), IPD fluctuations, and intentionality.

6.2 Study 2 (Chapter 4)

Study 2 sought to examine the utility of expert-identified critical variables with respect to expert-intermediate differences under representative conditions. In this way, the author and his supervisors determined whether the coaching-biomechanics interface is a useful platform for skill research. We also enhanced our understanding of skill through examining differences that occurred when the degree of representativeness changed. The variability in the normalised knee height at the cut reduced when a target was present, and this effect was greatest for the expert group. Similarly, the variability in the normalised knee height at the kick dropped considerably in the presence of a dynamic target. The differences for these variables between groups were not significant. Experts were less variable than the intermediates with respect to IPD at the cut. The utility of three of the identified variables for coaching and future investigation was demonstrated by modest differences in kicking conditions and with respect to expertise. In this sense, exploring movement through the coaching-biomechanics interface appears to have been moderately successful.

It was demonstrated in Study 2 that small improvements in the representativeness of tasks brought with them meaningful differences which deepen our understanding of how real-world tasks are performed. It was observed that there was a general lack of representativeness in the experimental designs of past research in taekwondo, making it difficult to compare results. For instance, further research is needed on the factors around scoring on the PSS, the technology that provides a unique affordance to taekwondo and is still a great mystery at this point in time. One of the coaches from Chapter 3 taught his athletes to kick the PSS a certain way for better accuracy, a hypothesis begging to be substantiated experimentally. The influence of foot velocity on scoring on the PSS in particular requires scientific scrutiny. While the present results did not support the critical role of foot velocity on effective kicking coordination, what the coaches termed as the ‘flick’ or whip may be characterised as an impulse wherein a high force is imparted on the target over a brief time period.[162] Effectively measuring kicking impulse on the PSS may shed more light on functional kicking coordination.

As a component of the study's representative research design, the participants kicked a live opponent outfitted with the body armour of the PSS. The participants themselves wore the PSS body armour and foot pads during data collection. The Daedo brand armours come in six sizes, but only one size was purchased for the project. Among some of the participants with shorter torsos, the armour obscured some of the retroreflective markers during the kicking action and caused difficulty in data collection and processing, limiting the usable participants and trials for analysis. Subsequent research should ensure properly fitted body armours for each participant.

In the current study, the opponent presented a representative affordance particularly in the DT condition by moving away from the participant's attack. A similar design was implemented by Kim et al.[104] in which the participants kicked an opponent wearing body armour in two conditions: static (ST) and erratic-dynamic (EDT). In the EDT condition, the opponent performed *ditgi* (a bouncing movement in place) within a specified distance. Since the opponent was not allowed to change their IPD with the kicker, the erratic movement (described as 'feinting moves') may have come from the upper body only (i.e., arm, torso, and head movements). In contrast, an opponent would most likely change their IPD during competition requiring the attacker to adjust accordingly. Further, an LED light attached to the opponent's armour signalled to the kicker to react as quickly as possible and kick the strike zone on the armour. This LED light is not commonly present on the PSS and created an affordance absent in competition. Moreira, Goethel, and Gonçalves[87] also increased representativeness by asking their participants to react to LED lights on two possible targets (the head and the torso) presented in a randomised order and timing to simulate stimuli in taekwondo matches. However, the design effectively reduced the task to a choice reaction problem not reflecting affordances that appear (and disappear) during combat. Another factor that limits generalisation to performance was that the target was a static instrumented training dummy. The present study sought to improve on these studies by increasing representativeness in genuine dyads. It seems germane to point out that representative studies need to reflect meaningful constraints for action, hence the need for expert opinions on what these constraints are.

As movement variability is rarely investigated, the current results can only be compared to the absolute values of past studies. These results are different to those of Landeo and McIntosh,[78] who found no differences in the intersegmental coordination of the roundhouse kick between kicking with no target and with a target. The authors hypothesised that their participants were able to kick consistently even without a target. However, the cut was also not executed, joint angles were not measured, and neither was a moving target presented for kicking. Quinzi, Sbriccoli, Alderson, Di Mario, and Camomilla[76] observed expert karate fighters execute roundhouse kicks without a target (NIRK) aimed at the head and on a static target (IRK) aimed at the torso. The NIRK trials produced significantly greater peak hip flexion and extension than the IRK. Another study examined the muscle activation patterns of the kicking leg of elite and amateur karateka under the same two conditions as the 2014 study.[182] The amateurs presented greater antagonist activation at the knee in both kicks. However, the experts showed a transfer of control from one joint to the other based on the task requirement, implying greater adaptability. Kim et al.[104] found skill-dependent variations in kicking coordination. They observed several variables of elite and sub-elite taekwondo athletes while executing the roundhouse kick on a live opponent under static and dynamic conditions. The elites demonstrated faster angular velocities and greater agonist-antagonist co-activation indices, particularly during the dynamic condition where they kicked an opponent performing irregular movements like those in competition. The dissimilarity in coordination between kicking conditions further highlights the value of presenting suitable targets to learners. Apart from the movement of the target, its size and density seem to influence movement coordination. For instance, Landeo and McIntosh[78] did not find any differences in peak linear and angular velocities in two taekwondo kicks performed with no target and three different targets. But there was increased joint stiffness, specifically at the knee, as the target became larger and denser. Therefore, the availability of different types of targets during the early stage of learning may help learners adjust their coordination solutions to better prepare them for more representative learning activities.

Study 2 highlighted the importance of IPD variations in the coordination of the cut-roundhouse combination as proposed by the Study 1 coaches. IPD seems to be a potential control parameter that guides the interaction through stable and unstable states in striking combative sports.[187] This interaction highlights the importance of the dynamic interaction between perception and action within a combative dyad, which has been scarcely investigated in full interaction contexts.[108] In their discussion of combat sports framed within ecological dynamics, Krabben et al.[187] described two combating athletes as a single dynamical system forming an interpersonal synergy. That is, the actions of one competitor (protagonist) are interdependent and constrained by those of the antagonist, which in turn, modifies the behaviour of the protagonist, and so on. The system self-organises into meta-stable states in which the more skilful athlete successfully directs and exploits the (in)stability of the whole system. This ability has been referred to as *brinkmanship*.[174]

In discussing fighter-fighter interactions permitted in experimental design within combat sports, Krabben et al.[187] reviewed three types of research: studies with a single participant with no interaction, those that involved opponents with restricted or choreographed behaviour, and studies that allowed full interaction between opponents. They observed that investigations with choreographed tasks may lack the representativeness of genuine combat because the observed pair may be acting cooperatively instead of antagonistically [187]. That may have been the case in the present study as the roles (i.e., the participant as the attacker and the researcher as the target), the kicking combination, the timing (i.e., the interaction was always initiated by the opponent), and the target region on the opponent (i.e., the PSS chest protector) were all set by the experimental design. Thus, elements of a truly representative task were missing. Forthcoming research could release more of these task constraints for better generalisability. For example, a more competitive design could be used in which both participants may switch attacking and defending roles at any time. While 3-D data collection may be even more challenging in this manner, perception-action couplings would be more representative of the performance setting and would provide valuable information on affordance emergence and decay.

The information surrounding affordances in combat sports is yet another area that will greatly advance knowledge and practice. Kimmel and Rogler[174] identified affordances in aikido via explication interviewing and think-alouds among coaches of different expertise. Unlike the striking style of taekwondo that mostly depend on visual cues, aikido affordances are subject to visual cues, as the attacker (*uke*) approaches the defender (*tori*), as well as proprioceptive information as the IPD closes in for grabbing and throwing.[174] Kimmel and Rogler[174] organised the level of perception to three timescales of affordances. Global task affordances pertain to the overall goal of the bout, which is to break the uke's balance and bring them to the ground. The information rests on how stable the uke's centre of mass is. Secondly, transitional main affordances indicate switches between elements of an interaction that may shape the succeeding actions. In aikido, these affordances would take the form of pressure and resistance changes of the uke that will signal adaptations to the technique. Lastly, between transitions, micro-affordances offer feedback to the precision of the throw. Skilled aikido performance requires perception and adaptation to these affordances. Kimmel and Rogler[174] also pointed to the experts' aptitude of concealing affordances from the attacker and providing false affordances; and combined these qualities into what they referred to as brinkmanship. It was not clear how the authors' conceptualised aikido in a genuine antagonistic context as the style was developed primarily for self-defence. That is, in practice and in freestyle sparring, the tori and uke roles are pre-set, unlike the constant role-switching in an authentic combative setting. It would be intriguing to examine how brinkmanship would manifest itself in a genuine striking combative environment like taekwondo. Likewise, coaches might develop problem-solving tasks to develop brinkmanship to increase the chances of victory and uplift the sport's profile on the Olympic stage.

Gaze anchoring research has given some insight on affordances and point to possible future research. Hausegger, Vater, and Hossner[188] used an eye-tracking system to measure the gaze positions of fighters from two different martial arts while defending against randomised attack patterns. Expert athletes in taekwondo, a style that uses predominantly kicking attacks, anchored their gaze lower on the opponent's body than the qwan ki do (a kung fu style that uses both arms and legs) experts. Regardless of style, all the athletes fixed their gaze around the shoulder or head level and used their peripheral vision to perceive the movements of the attacking limb/s. However, the height of the gaze was affected by the participants' native style, particularly the peripheral cues of the expected attacking limbs to which they are attuned. The gaze anchors persisted before each attack and even during the first movement of the attack. The experimental design required the participants to react to the attacks only by moving back or blocking, instead of launching a counterattack as in an authentic bout. The attacks may have also lacked the intentionality of being successful at hitting the participant with expensive technology on their head and body. Thus, it would be fascinating to use similar technology in a more representative experimental design to explore information sources for affordances and the emergent couplings in both defensive and, more importantly, attacking contexts. For instance, some participants reported getting cues from the opponent's facial expression.[188] Various attack combinations, with and without preparatory movements, as well as differences between skill levels, could be compared in future combat sport research.

The initial criterion used for participant selection, the years of competition experience[26, 96, 203] may not have effectively distinguished between skill groups. Alternatively, success in competition may be a more appropriate criterion for expertise as used in several studies.[21, 81, 85] Additionally, some studies discriminated between skill levels by using the level of competition in which the athletes were participating. For instance, Pozo, Bastien, and Dierick[84] divided their participants into national and international standard karate athletes. The changing rules of competition taekwondo, and the functional adaptations that go with them, may be better reflected by these criteria in representative research designs. Furthermore, more participants and a greater number of observed trials will make a more robust analysis in future research.

6.3 Study 3 (Chapter 5)

The primary aim of Study 3 was to investigate the effects of a six-week representative learning intervention on the critical coordination variables and effectiveness of the taekwondo roundhouse combination. Coordinative changes were observed within a case-series design using a small cohort of intermediate participants. Following modest expertise-related differences in Chapter 4, we expected the variability of KAC, KAK, and IPDC to reduce as the representativeness of the task increased as it 'settled down' to a consistent, functional level.[83] None of the participants displayed the expected patterns in all three variables. Taken together, the limited implementation of the present learning intervention appeared to result in some expected expert coordination patterns in one variable and several unclear changes in two other critical variables. However, the changes in coordination did not produce clear immediate or lingering post-intervention scoring improvements.

Knowledge on the effectiveness of learning designs in combat sports needs strengthening as hardly any research was found on the subject. However, it is clear that the parameters of practice methods must first be clearly clarified; in particular, the purpose of the practice and the learner's skill level are paramount considerations. Repetition training of strikes without a target, for instance, may be used to stabilise the skills of novices and for *poomsae* competition. For combat or sparring purposes, however, practice within a dyad will allows the athlete to learn to perceive and adapt to the constraints within the context of an actual fight.[187] Sparring with a variety of opponents is likely to increase the learner's ability to adapt (i.e., brinkmanship), but the mechanism of the acquisition of this ability is poorly researched. Maier[126] previously demonstrated how a learner adjusted to different partners in learning a wing chun block-punch combination, and points to potential investigations in taekwondo and other styles.

Different training strategies can be used to observe critical variables in practice contexts, and the following studies offer ideas for coaches and researchers. BenitezSantiago and Miltenberger[204] used video feedback to improve acrobatic movements in capoeira. Novice learners learned the movements more quickly with video and coaches' feedback than with regular practice. A version of this approach was used in the present study as the coaches were shown the videos of the participants at the end of each session for their subsequent progression, although no direct feedback was given to the learners to allow them to self-organise their movement coordination to the task requirements. Video feedback can easily be adapted to both technique and tactical training and could be implemented for immediate and long-term feedback. Videos can also be used for self-reflection, particularly for more advanced athletes practicing complex techniques or match analysis. Finally, a 'video diary' may be compiled for each athlete to chart their progress throughout their career to offer an alternative source of motivation other than their win-loss record.

One of the limitations of providing video feedback was the time spent filming the clips, downloading them to a laptop, viewing and commenting.[204] A possible quicker alternative is auditory feedback, in which feedback is provided via an auditory device to reinforce the correct steps during technique learning. Krukauskas, Miltenberger, and Gavoni[205] used a handheld clicker as a reinforcer each time the learner performed a correct step in learning the right cross among novice mixed martial artists. The intervention was administered over several trials that focus on only one step of the whole skill at a time and no additional feedback was given. All the participants improved their right cross significantly after the intervention, and their performance persisted during the follow-up. Auditory feedback could speed up skill acquisition and subsequently reduce the number of sessions to improve skills among novices. As soon as the skill stabilises, constraints should be manipulated to allow the learners to adapt to more representative conditions. The progression of the practice tasks found in this thesis may be used as a guide for skill advancement.

In selecting constraints to manipulate during practice, coaches may use the athlete's acute fitness level to elicit functional performance adaptations. Specifically, peripheral and/or central fatigue similar to competition may be induced in practice to allow athletes to adjust their coordination to achieve the task outcomes. Quinzi, Camomilla, Di Mario, Felici, and Sbriccoli[196] observed lower limb kinematics and muscle activation of karate practitioners during repeated roundhouse kicks. Results revealed that the athletes changed their joint coordination and muscle activity over 20 repetitions of the kick. It was recommended for coaches to augment training with continuous repetitions as karate competitions requires proper technical execution. However, in other combat styles where scoring points is the overriding concern (such as taekwondo), allowing the athletes to modify their movement organisation to achieve the performance outcome would be a more relevant approach. In practice, some training sessions could be organised in which sparring be placed near the end in order for the learners to accumulate fatigue, a common occurrence in multi-day tournaments. While in some sessions, scenario training could be placed earlier for less cognitive fatigue. Session organisation can easily add to training variability that fighters need to further develop their brinkmanship.

Taekwondo, like most martial traditions, organises techniques to be learned by skill level (i.e., belt or grade level).[206] Learners are limited by the techniques within their belt level until they take a promotion test for the next level. Techniques are taught progressively over the levels so that the learner may explore more complex skills as they advance. While the promotion test skill requirements are set by the Kukkiwon (World Taekwondo Headquarters), the curriculum to teach these skills are not. Therefore, task simplification could be applied at any belt level to introduce increasing levels of variability to the task constraints (see Appendix C). Some of the grading test requirements imposed by the Kukkiwon[207] such as *poomsae* and *kyokpa* (breaking), reflect a disconnect with the demands of Olympic competition, revealing the dual nature of taekwondo—one that is partly entrenched in tradition as a martial art and the other struggling to legitimise itself as a global sport.

The numerous adaptations to coordination in the dynamic target condition in the present study support the value of dyadic training, and specifically with a moving partner. As implemented in Study

3's learning design, the type of target may be altered based on the skill of the learner and the technique to be learned. For example, learners in the coordination stage of learning may practice their strikes on kick pads or shields for safety purposes.[4] As they stabilise their coordination patterns, fighters can move on to striking their armoured partners. Whatever the type of target is, it is crucial that it moves.

Another feature of the study's learning design is the limited number of task repetitions (10) that reduced the risk of neuromuscular fatigue.[208] Changing constraint parameters for each repetition simulated the dynamic performance context, following Bernstein's concept of 'repetition without repetition'.[43] In practice, pauses in between repetitions might be used by the coach to allow athletes to process their performance through self-reflection and exchange of ideas with their partners. Conducting practice sessions in this manner is different from traditional repetition practice that aim to stabilise skills through numerous repetitions.[133]

The most representative target for sparring practice would most likely be a partner equipped with a PSS. However, as previously mentioned, the cost of this technology may be prohibitive for most clubs. To help alleviate expense, instructions in practice sessions can serve to constrain the order and control parameters of a technique's coordination pattern.[116] Based on Hristovski's[45] work on boxing, one of the crucial control parameters in taekwondo could be the scaled distance to the target, while two important order parameters would be the direction of the foot-target impact as well as the frequency and relative phase of the kicking activity. Precise instructions for scenario tasks can manipulate these parameters by controlling task constraints such as techniques to be delivered (type, relative phase, frequency), target movement (established to random), and impact force (i.e., enough to score). To highlight the effect of instructions on kicking performance, dissimilarities to kicking coordination from different instructions (i.e., regular or 100% modes) have been observed in a taekwondo kicking combination.[119] In practice, safety can be enhanced by doing 100% efforts on pads, shields, or opponents wearing two *hogul* (or extra padding). Head kicks may be practiced on moveable target mannequins. Scenario tasks may be progressed from set defender-attacker roles to authentic antagonist roles such as in the 'golden point' setting. In the absence of the PSS, the traditional estimate of an effective kick, the audible pop on the *hogul*,[18] may be used for instruction and feedback. In fact, quantitatively comparing this relatively old-fashioned gauge to scoring effectiveness on the PSS may greatly benefit financially challenged taekwondo clubs.

Finally, representative training can be enhanced by setting up sparring practice in an authentic competitive setting. Organising small inter-club competitions will better simulate the physiological responses[123] and emotional engagement[118] found in performance contexts. However, care must be taken in scheduling such mini-competitions to reduce the risk of injury and burn-out.

6.4 Conclusion

With an ecological dynamics framework, this thesis used a more representative research design to examine a model for the coaching-biomechanics interface. Study 1 produced candidate critical variables from a coach-researcher collaboration, which were validated by two other coaches on their usefulness. Study 2 further affirmed the utility of three candidate variables to improve kicking performance in dynamic contexts among intermediate fighters. The other variables with marginal to no statistical differences may have been a result of limitations of the research design. Follow-up investigations may show these variables could be important for researchers in the laboratory as they are for coaches in the gym. Study 3 combined elements of ecological dynamics and expert knowledge in the learning design. The research design incorporated additional representative elements, particularly in seeking out coach input on training progression. The study provided some evidence that two of the participants were improving as expected, but the research design and intervention duration may have prevented drawing a clear conclusion. Taken together these studies support the use of expert coach knowledge as a device for analysis and communication between sport scientists and coaches. These conclusions are however limited by the availability of relevant expertise, which in turn left several conclusions underpowered. More numbers in the studies would have been both more revealing and more conclusive.

This thesis applied modern perspectives to what may be regarded as a 'traditional sport' which is now experiencing significant change since its inclusion in the Olympics. The rapid flux in the sport seems to necessitate a much more flexible pedagogical approach, such as one that is founded on ecological dynamics. A bit like combatants in a fight, coaches must be constantly on their toes to gain the upper hand. Much has been learned about taekwondo from this thesis, some of which may be generalised to other combat sports. Rich possibilities for both research and practice design have been proposed. However, the author would like to highlight the coaching-biomechanics interface, the fruitful collaboration between researchers and coaches, an approach that hopefully inspires more efforts to close the gap between research and practice. Opening minds within traditional martial arts may be difficult but increasing the amount of contextually appropriate research could help greatly in this regard. To some extent, the success of this thesis is grounded on approaching coaches at the outset, seeking to adapt existing codified theoretical knowledge with their help. Even with the limitations of this thesis, there is the potential to light the way towards the phenomenology of future research on each step of the model: knowledge capture, knowledge verification, and knowledge application. Despite some difficulties, future researchers and coaches should find ways to meet halfway and this thesis optimistically points towards that goal. Bruce Lee[202] steered us, both coaches and researchers, towards the proper frame of mind:

> 'By an error repeated throughout the ages, truth, becoming law or faith, places obstacles in the way of knowledge. Method, which is in its very substance ignorance, encloses truth within a vicious circle. We should break such a circle, not by seeking knowledge, but by discovering the cause of ignorance.' (p. 202)

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APPENDIX A

INTERVIEW PROTOCOL AND PLANNED QUESTIONS

Interviewer: ___________________________________

Interviewee: ___________________________________ Gender: __________

Date & Time: ___________________________________ Location: _________

Protocol

My name is Luigi Bercades. I am doing research so that I can gain the understanding of expert coaches' concept of successful taekwondo performance, particularly the roundhouse kick. The study will involve coaches from New Zealand and other countries.

Thank you for your willingness to participate in this research project. Have you read the information provided to you, entitled "Participants' Information"? Before we begin the interview, I would like to reassure you that this interview will be confidential and the tape and transcripts available only to my research supervisor and me.

Do you voluntarily agree to participate in this interview?

Do you mind if I videotape the interview?

(If yes) If there is anything you don't want me to record; just let me know and I will turn off the camera.

Written and oral reports and other material coming out of this study will present only aggregate data and information. Excerpts of this interview may be made part of the final research report. Under no circumstances will your responses, name or identifying characteristics be included in this report. Do you have any questions I can answer for you before we begin?

Is it all right for me to turn on the camera now?

Task One interview questions

Can you tell me a little about your background in tkd?

Critical factors influencing tkd performance

What are the factors that influence tkd performance?

1. What determines if a fighter is performing well in a fight?
2. How do you pick up on (detect/know) this?
3. How would you rank these factors in terms of importance?
4. How would the level of skill affect how these factors influence performance?
    a. What are the differences/similarities in changes/processes between skill grades?
    b. How do you know?

Perceptual information used

What makes things happen in a fight?

5. What starts attacking sequences?
6. How does a fighter know when to counter?
7. Can you tell me more about a particular time when… (example from something the participant has said)?

How do you change? What tells you?

When tkd fighters need to make a change in performance, what perceptual information do they use to make this decision and how do they judge the outcome of this change?

8. How do you know when a fighter needs to make a change in his/her performance?
9. Why do you think this?
10. How did you learn this?
11. What role do you think the opponent and/or environment has in influencing a fighter's movements?
12. Do you use different signals for making different changes for the fighter?
13. What are these?
14. How would the skill level of the fighter affect the use of these signals?
15. What reinforces you to keep using this information about a fighter's performance?
16. How do you train a fighter for these things?

Technical adjustments

What are the adjustments necessary to adapt to the opponent?

17. What part/s of their performance do you think fighters need to be able to control/change well themselves?
18. Why do you think this/these part/s?
19. How would you rate these parts in terms of importance?
20. How do you teach the fighter to make that change?
21. What are the signs that the fighter has made the changes?
22. For the roundhouse kick, what part/s do you think fighters need to be able to control/change well themselves?
23. Why do you think this/these part/s?
24. How would you rate these parts in terms of importance?
25. How do you teach the fighter to make that change?
26. What are the signs that the fighter has made the changes?
27. Would the fighter's skill affect the parts they need to adjust?

<u>Task Two interview questions</u>

Common components of the kicking combination relative to skill level

How well is the fighter performing the combination?

1. What influences the advanced fighters' kicking performance? What sets them apart from less skilled fighters?
2. What's common or different amongst them?
3. What stands out when you look at… (Elaborate on the mentioned factors)?
4. How do these factors affect kicking performance?
5. What can be changed to improve their performance?
6. How can these changes be taught? How do you think these things are taught incorrectly?
7. What are the factors that influence the novice fighters' kicking performance? What sets them apart from more skilled fighters?

8. What’s common or different amongst them?
9. What stands out when you look at… (Elaborate on the mentioned factors)?
10. How do these factors affect kicking performance?
11. How do you pick up on potential ability?
12. What can be changed to improve their performance?
13. How can these changes be taught? How do you think these things are taught incorrectly?

Differences in skill levels (follow-up or summing-up questions)

14. Based on the footage that you have seen what are the key differences in performance between skill levels?
15. What part/s of the kicking performance can be improved?
16. What recommendations would you give for the development of…

APPENDIX B

UNIT PLAN FOR THE TAEKWONDO CUT-ROUNDHOUSE COMBINATION

Title: Taekwondo cut-roundhouse combination

Purpose: To implement constraints-driven tasks to improve the performance of intermediate athletes on the kicking combination. To assess the effectiveness of these tasks.

Description: Progressive tasks to improve coach-identified critical factors for the successful performance of the kicking combination.

Grade level: Intermediate

Duration: 12 sessions. Approximately 15-30 mins per session.

Objectives:

- To improve kicking efficiency by better control of the athlete's scaled distance to the opponent. Scaled distance is the ratio of the physical distance and the leg length of the attacker to the opponent.[45] It is what the coaches described as the proper distance so that the kick is not short (i.e., not fully extended).
- As a corollary to the above, kicking coordination can be developed by ensuring sufficient impact energy to score on the PSS. The coaches described this as kick speed, snap, or flick. Biomechanically, an increase of the peak velocity of the proximal and distal segments is sought. However, the distal segmental coordination needs to be stable to be accurate. Hence, fluctuations in the proximal segments (knee-hip and hip-trunk) would have to adjust for velocity-transfer and target acquisition.[46]
- Supporting-leg stability is another factor to be improved. Coaches mention its importance in the delivery and recovery of the kick, particularly in preparation for a follow-up kick. Balance while in contact with the opponent was also deemed crucial. There has been mention of the contribution of the push off the supporting foot to the kick's peak force.[82, 100] Greater rotation of the supporting leg has also been associated with greater mobility for the kicking leg[74] and overall stability.[119] Rotation of the supporting foot is also vital in preventing torque-induced knee injuries.[100, 119]
- The height of the cut kick was also a common factor mentioned by all coaches. A high cut (i.e., with the foot at waist level) has tactical advantages, such as offering a shield against attacks to the body, and more kicking options (i.e., body or head kick). A quick recovery after the kick will not only be good preparation for a follow-up kick but will also aid in overall stability.

Organisation of progression of constraints

	Drill type				
Progression level	Paddle (1)	Armour (2)			
Level 0.0	Movement (static target)				Set rhythm (2-5 seconds rest between trials)
Level 0.1	Dynamic target	Set distance (the distance of a regular footwork slide)	Set direction (forward and backward)	Set pattern (alternating forward and backward)	Set rhythm
Level 0.2	Dynamic target	Set distance	Set direction	Random pattern	Set rhythm
Level 0.3	Dynamic target	Set distance	Set direction	Random pattern	Random rhythm (ranging from no rest to more than 3-5 seconds)
Level 0.4	Dynamic target	Set distance	Random direction (all angles of approach)	Random pattern	Random rhythm
Level 0.5	Dynamic target	Random distance (ranging from no movement to wider than normal slide)	Random direction	Random pattern	Random rhythm

Description of tasks

Distance discovery	
Expected student objectives & outcomes: • To learn each individual's scaled distance. Or, as Coach 4 put it, "master the length of one's legs" • Students will discover the appropriate coordination and distance to impart sufficient speed	**Materials needed:** Paddles; hogul

and impact on a paddle for a "score" • The athlete learns to adapt to increased variability • The athletes learn to adjust their scaled distance in a more representative task	
Distance discovery 1.0	1. Athletes will pair up with a paddle between the two 2. Each one will perform 10 cut-roundhouse combinations on the paddle. The holder will stand statically. 3. Each kick will be followed by a brief rest (3-5 seconds) 4. The aim is for each kick to "score". That is, for their kick to produce an audible sound on the paddle. 5. After completing the kicks on one leg, the athletes will switch roles and repeat the drill on the partner. 6. The drill will be repeated on the other leg **N.B.** After the instructions, do not give additional external feedback unless there is a risk of injury
Distance discovery 1.1	1. The set-up is the same as 1.0 (above) 2. This time, the holder of the pad will slide back and forth alternatively for each trial (i.e., dynamically). That is, sliding forward for odd-numbered trials, and sliding backward for even-numbered ones. 3. The kicker will need to adjust his/her distance to be able to score. 4. The athletes will exchange roles after 10 trials, and then, exchange kicking legs.
Distance discovery 1.2	1. This drill is similar to 1.1 2. The only difference is the random changes of the pattern instead of the set pattern of 1.1
Distance discovery 1.3	1. This drill is similar to 1.2 2. The additional variable factor is the random changes in the rhythm (i.e., ranging from no rest to more than 3-5 seconds)
Distance discovery 1.4	1. Same set-up and performance as 1.3 2. The additional variable this time is direction. That is, the paddle holder will present the target in a random

	sequence in terms pattern, rhythm, and direction (i.e., angles of approach).
Distance discovery 1.5	1. Same set-up and performance as 1.4 2. The additional variable this time is distance. That is, the paddle holder will present the target in a random sequence in terms pattern, rhythm, direction, and distance (i.e., ranging from no movement to wider than normal slide).
Distance discovery 2.1	1. Get the athletes to armour up and pair up 2. The rest of the set-up is like 1.1
Distance discovery 2.2	1. Get the athletes to armour up and pair up 2. The rest of the set-up is like 1.2
Distance discovery 2.3	1. Get the athletes to armour up and pair up 2. The rest of the set-up is like 1.3
Distance discovery 2.4	1. Get the athletes to armour up and pair up 2. The rest of the set-up is like 1.4
Distance discovery 2.5	1. Get the athletes to armour up and pair up 2. The rest of the set-up is like 1.5
Single-leg balance	
Expected student objectives & outcomes: • Increase the stability of the supporting leg for increased mobility, kicking effectiveness and faster recovery • The athlete learns to integrate maintenance of scaled distance with single-leg stability • The athlete learns to adapt to increased variability	**Materials needed:** Paddles; hogul
Single-leg balance 1.0	1. Similar to Distance discovery 1.0 (i.e. static), but the athletes start from a cutting position (i.e. knee up)
Single-leg balance 1.1	1. Set-up is like Single-leg balance 1.0, but pattern is set like the Distance discovery 1.1 drill
Single-leg balance 1.2	1. Set-up is like 1.1 2. The only difference is the random changes of the pattern instead of the set pattern of 1.1
Single-leg balance 1.3	1. Set-up is like 1.2

	2. The additional factor is the random changes in the rhythm (i.e., ranging from no rest to more than 3-5 seconds)
Single-leg balance 1.4	1. Set-up is like 1.3 2. The additional variable is the random changes in the direction (i.e., all angles of approach)
Single-leg balance 1.5	1. Set-up is like 1.4 2. The additional factor is the random changes in the distance (i.e., ranging from no movement to wider than normal slide)
Single-leg balance 2.1	1. Get the athletes to armour up and pair up 2. Set-up is like Single-leg balance 1.1
Single-leg balance 2.2	1. Get the athletes to armour up and pair up 2. Set-up is like Single-leg balance 1.2
Single-leg balance 2.3	1. Get the athletes to armour up and pair up 2. Set-up is like Single-leg balance 1.3
Single-leg balance 2.4	1. Get the athletes to armour up and pair up 2. Set-up is like Single-leg balance 1.4
Single-leg balance 2.5	1. Get the athletes to armour up and pair up 2. Set-up is like Single-leg balance 1.5
Cut and recovery	
Expected student objectives & outcomes: • The athlete learns to have a high and tight cut and a quick recovery • Increase the stability of the supporting leg for increased mobility, kicking effectiveness and faster recovery • The athlete learns to adapt to increased variability • The athletes learn to adjust their scaled distance in a more representative task	**Materials needed:** Paddles; hogul, hurdle
Cut and recovery 1.0	1. Set up a one-meter-long barrier that is approximately the height of the knee of the athlete. A piece of string strung between two chairs would be an example. 2. Place the barrier approximately one meter away from a wall. The actual distance will vary with the height

	(and thus, the stance width) of the athlete. The distance should allow him/her some room to slide forward and backwards naturally. The barrier will constrain the height of the cut and the wall will limit the posture of the learner. 3. The athlete stands between the barrier and the wall, and a partner stand in front of him/her with a paddle 4. The task is for the athlete to perform and recover from a front-leg kick without hitting the barrier with his/her kicking foot 5. Trials will be performed the same way as the Distance discovery 1.0 drill
    	
Cut and recovery 1.1	1. Set-up is like 1.0, but pattern is set like the Distance discovery 1.1 drill
Cut and recovery 1.2	1. Set-up is similar to 1.1 2. The only difference is the random changes of the pattern instead of the set pattern of 1.1
Cut and recovery 1.3	1. Set-up is like 1.2

	2. The additional variable is the random changes in the rhythm (i.e., ranging from no rest to more than 3-5 seconds)
Cut and recovery 1.4	1. Set-up is like 1.3 2. The additional factor is the random changes in the direction (i.e., all angles of approach)
Cut and recovery 1.5	1. Set-up is like 1.4 2. The additional factor is the random changes in the distance (i.e., ranging from no movement to wider than normal slide)
Cut and recovery 2.1	1. Get the athletes to armour up and pair up 2. Set-up is like Cut and recovery 1.1
Cut and recovery 2.2	1. Get the athletes to armour up and pair up 2. Set-up is like Cut and recovery 1.2
Cut and recovery 2.3	1. Get the athletes to armour up and pair up 2. Set-up is like Cut and recovery 1.3
Cut and recovery 2.4	1. Get the athletes to armour up and pair up 2. Set-up is like Cut and recovery 1.4
Cut and recovery 2.5	1. Get the athletes to armour up and pair up 2. Set-up is like Cut and recovery 1.5

Situational sparring progression

Level 1	Level 2	Level 3
1. Athletes armour up and pair up 2. Sparring area is the corner of the regulation 8 x 8-meter ring 3. Set the time of the round to 30 seconds 4. Have one of the pair attempt to score as many points as possible on the hogul using the cut-roundhouse combination 5. The other athlete will be the defender and not allowed to attack or counter-attack, but must avoid being scored on	1. Athletes armour up and pair up 2. Sparring area is the whole regulation 8 x 8 meters 3. Set the time of the round to 30 seconds 4. Have one of the pair attempt to score as many points on the hogul using the cut-roundhouse combination 5. The attacker will keep track of their ‘score’ as evidenced by an audible sound on the armour. If the PSS is available, base the score on the actual points	1. Athletes armour up and pair up 2. Sparring area is the whole regulation 8 x 8 meters 3. Set the time of the round to 30 seconds 4. Have both athletes attempt to score on each other using the cut-roundhouse combination 5. The attackers will keep track of their ‘score’ as evidenced by an audible sound on the armour. If the PSS is available, base the score on the actual points 6. Do 2-3 rounds

6. The defender starts at the corner 7. The attacker will keep track of their 'score' as evidenced by an audible sound on the armour. If the PSS is available, base the score on the actual points 8. Switch roles 9. Do 2-3 rounds	6. Switch roles 7. Do 2-3 rounds

N.B. Progression of each athlete will be based on their performance on the preceding drill. Competence will be determined by the consensus of at least two coaches based on the objectives of each drill. Each athlete will be videotaped performing each drill. The video clips will then be reviewed by the coaches at the end of each session to determine their competence.