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Sports Science-Based Research on the Sport of Muay Thai: A Review of the Literature

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Abstract

This article aims to provide a systematic review of the sports science-based research that has been done on the sport of Muay Thai boxing. The first phase of the process involved a search made using several research databases, using specific keywords. Muay Thai related articles that were selected were then reviewed and categorized into classifications based on their major area of study. The second phase involved a critical review of 14 published articles that fell into the 4 major areas of study in sports science (strength & conditioning, sports physiology, sports biomechanics, and sports psychology). This critical review provided insight and discussions into approaches, limitations, and conclusions of each research publication, and how they may relate to each other. From the review, it can be concluded that Muay Thai sports science-based research has been far from sufficient. The near non-existence of physiological, biomechanical, and psychological findings limits scientifically-based strength and conditioning applications which, if implemented, may improve performance and reduce risk of injury. Future studies should focus on current Muay Thai athlete profiling (physiologically, biomechanically and psychologically) at all levels, to provide baseline findings which are much needed when developing strength and conditioning programs. Research concentrating on interventions should then be focused on.

Keywords: Muay Thai, physiology, biomechanics, psychology, physical conditioning

Introduction

Muay Thai, literally can be translated as Thai Boxing, is one of the most popular sports in Thailand, and one of the cultural exports of Thailand, and has seen huge impact on the world of combat sports and commercial trends.

Muay Thai, in comparison with other types of combat sports, uses almost all body parts, producing 8 points of contact (fists, elbows, knees, and feet), and includes fighting techniques such as punches, elbows, knee strikes, kicks, and grappling [1,2]. Other popular combat sports, such as boxing or taekwondo, use only 2 (boxing: fists) or 4 (taekwondo: fists and feet) points of contact [3,4]. Because of this difference, other physical conditioning programs and training skills may not be suited to Muay Thai fighting.

Thus, to provide an insight on current status of sports science-related research that has been done so far on the sport of Muay Thai, a review of the literature is needed. We suggest that this needs future study in the Muay Thai fraternity, both within and outside of Thailand.

Materials and methods

A search was made on the Google Scholar database between 27th to 28th January 2016, using specific key words (Muay Thai and muaythai). The key word "Muay Thai" generated about 2,730 results. The results generated included all other publications that had the words "Muay Thai' or "muaythai" in them. Searches were also made on other databases such as ProQuest, Ebscohost, and Scopus. Other key words, such as 'Thai kickboxing' or 'Thai boxing', were also used. The search and re-search in all database yielded near-similar results.

Selection criteria for inclusion were made to eliminate all non-related or irrelevant publications. The main criteria for inclusion in phase one was that the publications had to be an original research paper specifically written on Muay Thai, with at least one of the specific sub-criteria, as below:

(a) The participants involved were Muay Thai-trained or practiced Muay Thai skills and techniques.

(b) Interventions prescribed simulated actual Muay Thai conditions or in actual Muay Thai competition set-ups.

(c) Comparisons and discussions made were all for the purpose of the sport of Muay Thai (i.e., not just a mere mention, without any focus on Muay Thai),

(d) Outcomes provided additional scientific-based information for the body of knowledge in the sport of Muay Thai.

Other than that, the articles had to be in the English language, or with translation into the English language, and the full text had to be retrievable by any online means. All publications fulfilling the stated criteria were then selected for the next phase of the review process. Elimination of search results was due to them not fulfilling at least one of the 4 sub-criteria.

Criteria for inclusion in phase 2: All articles selected in phase one were put into specific areas of classification, which were based on the foundational area of studies for Sports Science. Five areas of classification were suggested for all articles found: (a) Strength & Conditioning; (b) Sports Physiology; (c) Sports Biomechanics; (d) Sports Psychology; (e) Other areas outside sports science (including sports medicine and sports management). From the 5 areas of studies, only papers that were categorized in the fields of strength & conditioning, sports physiology, sports biomechanics and sports psychology were chosen to be critically discussed in this paper, with **Table 1** summarizing the content of each publication. Publications that fell in the 'Other areas outside sports science' category, although not discussed thoroughly, are presented in later part of this review.

Results and discussion

Based on **Table 1**, a critical review of the studies that fulfilled all the criteria are presented as follows, based on the selected area of studies as indicated earlier.

Table 1 Publications in Sports Science that focus on the sport of Muay Thai.

No.	Authors, Publication year [refs]	Number of participants, Age range, Height and weight, Experience level	Study design	Outcomes/Conclusions	Classification, Inclusion reason(s), Types of publication
1.	Crisafulli *et al*. 2009 [6]	n = 10 male Muay Thai athletes; 23.7 ± 1.5 yrs; 174.3 ± 0.0 cm; 65.1 ± 1.2 kg; 2 yrs regular competition.	- Experimental profiling during simulation Muay Thai match. - Two sessions. Preliminary incremental exercise test for anaerobic threshold & maximal oxygen uptake. - Second session of fighting simulation test (3 rounds with 6 attacks & 6 defensive actions per round) (15 sec per action = 180 sec per round), 1 min sitting rest in between rounds. - Final effort levels were evaluated using a scale of 1 (not similar) to 5 (very similar), compared with normal fights. All tests conducted between 0900 and 1400 h in a room set at a temperature of 22 °C with relative humidity of 50 %.	**Preliminary test (profile):** VO_{2max} 48.52 ± 1.7 ml·min·kg^{-1} HR_{max} 182.9 ± 1.6 bpm $VO_{2\ AT}$ 30.8 ± 1.6 ml·min·kg^{-1} HR_{AT} 137.5 ± 4.5 bpm **Simulated Match:** - Average energy expenditure 10.75 ± 1.58 kcal.min^{-1}, - metabolic equivalents 9.39 ± 1.38 - Immediate increase in $CO_{2\ excess}$ in round 1, with maximum value 636 ± 66.5 mL·min^{-1}. Value decreased gradually afterwards. **Conclusion:** high involvement of both aerobic metabolism and anaerobic glycolysis.	Sports Physiology. fulfils all the inclusion criteria. Original research article.
2.	Cappai *et al.* 2012 [7]	n = 20 skilled male Muay Thai athletes; 24.6 ± 1.2 yrs; 176.1 ± 1.3 cm; 69.4 ± 2.2 kg trained 8 - 10 hours/week, upper-middle level (12 international, 8 national levels).	- Experimental profiling during actual Muay Thai match. - Two sessions. Preliminary incremental exercise test for anaerobic threshold (AT) & maximal oxygen uptake. - Second session of Muay Thai match test (4 rounds of 2 min per round), 1 min recovery in between rounds. - Heart rate and blood lactate taken pre, during and post match. - Video camera recorded all matches for match analysis. - Match conducted between 4-9pm in regular Muay Thai ring.	Preliminary Test (profile) VO_{2max}: 54.3 ± 1.4 ml·min·kg^{-1} $VO_{2\ AT}$: 30.8 ± 1.7 ml·min·kg^{-1} (~ at 50 % of VO_{2max}) Mean max HR 187.2 ± 0.5 bpm HR at AT: 168.4 ± 1.3 bpm - Total 10 matches filmed and analyzed. Total time in: - Study phase: 47.89 ± 4.17 sec - Clinch attacks: 24.58 ± 4.64 sec - Attacks at distance: 47.5 ± 5.9 sec Average heart rate: 178.9 ± 0.3 bpm Average blood lactate - Round 1: 6.02 mmol·L - Round 4: 12.55 mmol·L - All rounds average: 9.72 ± 0.6 mmol·L **Conclusions:** Winners and losers used similar physical effort and number of techniques executed. Winners used more effective attacks.	Sports Physiology. Fulfils all the inclusion criteria. Original research article.
3.	Rossi, de Oliveira, da Silva Borges, & Malavazzi, 2011 [8]	n = 30 male Muay Thai practitioners. Age above 18 yrs 12 months training experience	- Experimental profiling. - Instead of all 30 participants being tested, only 10 tested for anthropometry, and 20 for dietary intake. - Study was done at 3 gyms in Sao Paulo City, Brazil. - Body weight & height pre and post training. - Four sites skinfold for body composition. - Sweat rate and water loss	**Anthropometry n = 10:** Age 23.8 ± 5.3 yrs; Height 177.1 ± 4.9 cm; Weight 70.9 ± 9.7 kg BMI 22.59 ± 2.88 kg·m^{-2} Body fat 15.4 ± 4.3 % **Hydration status n = 10** Sweat rate 12.6 ± 8.8 ml·min^{-1} Water intake 719.0 ± 335.3 mL Weight loss 1.5 ± 0.9 % **Dietary intake (n = 20)**	Sports Physiology (nutrition). Fulfils criteria. Original research article.

No.	Authors, Publication year [refs]	Number of participants, Age range, Height and weight, Experience level	Study design	Outcomes/Conclusions	Classification, Inclusion reason(s), Types of publication
			percentage relative to initial weight calculated. - Three days dietary records inclusive 1 weekend day, 1 training day & 1 non-training day.	Energy 3202.50 ± 730.65 kcal Carbohydrate 52.05 ± 6.65 % Protein 19.70 ± 5.12 Lipids 27.67 ± 5.15 % *Other micronutrients listed in the article. **Conclusion:** Adequate nutrition and appropriate body composition, but protein and macronutrient intake inadequate.	
4.	Krick & Raschka, 2012 [9]	n = 70 male (30 Muay Thai fighters, 40 physical education students). n = 30: 177.2 cm n = 40: 184.1 cm	Experimental - Anthropological measurement - Two groups of Muay Thai fighters and physical education students - Two subgroups of experienced and less experienced	Experienced Muay Thai fighters are significantly smaller than the experienced students majoring in physical education **Conclusion:** The small size of experienced Muay Thai fighters have more advantages in moving quickly and being able to make faster and harder attacks	Sports Physiology (nutrition). Fulfils criteria. Original research article.
5.	Sidthilaw, 1996 [10]	n = 10 male (80±23.6 kg; 1.76±8 cm; 23±15.1 months of experience)	- Three dimensional movement analysis and bag kicking tests using accelerometer were conducted to collect data. - Variables: Kinetics (peak force and impulse) and kinematics (angular velocity) - Leg strength: Hip flexion and knee extension isokinetic measurement.	- Knee extension torque (193.8±33.7 Nm) - Hip flexion torque (159.3±38.2 Nm) - Mean peak force of low, middle, and high level (6702±3514 N; 7420±3477 N; 5618±3253 N) - Mean impulse of low, middle, and high level (42.9±15 Ns; 50.2±19 Ns; 40.6±16 Ns) - Ankle final linear velocity of low, middle, and high level (6.9±0.8 m/s; 7.1±1.1 m/s; 6.8±1.2 m/s) - Peak force and impulse were correlated to final velocity of the ankle	Sports Biomechanics. Fulfils criteria. Full thesis available online.
6.	Silva, Del Vecchio, Picanço, Takito, & Franchini, 2011 [11]		- Observation analytical study - Thirteen matches of 2 amateur kick boxing and Muay Thai tournaments - Kinovea was used to analyze the data. - Time motional analysis including Observation, Preparation, and Interaction periods - Effort:Pause (E:P) analysis	- Six Muay Thai matches (73 Observations, 77 Preparations, 94 Interactions) - Seven Kick Boxing matches (107 Observations, 82 Preparations, 136 Interactions) - E:P of Kick Boxing (6 sec: 12 sec; 1:2) and Muay Thai (9 sec: 12 sec; 2:3) - The average effort of Kick Boxing (5.5 sec) and Muay Thai (8.7 sec) was significantly difference. - Kick boxing average pause block (12.3 sec) - Muay Thai average pause block (12.0 sec).	Sports Biomechanics.
7.	Trial, 2013 [12]	n = 10 amateur martial arts athletes; 23±5 yrs; 1.8±0.1 m; 73.3±11.4 kg; 5.9±5.4 yrs experience.	The subject performed 6 continuous knee strikes with - double collar tie clinching - double under hook clinching 3 min break between both clinches.	Hip joint angle between both clinching positions were significantly different. - Right double collar 109.0˚±15.0˚ - Right double under hook	Sports Biomechanics.

No.	Authors, Publication year [refs]	Number of participants, Age range, Height and weight, Experience level	Study design	Outcomes/Conclusions	Classification, Inclusion reason(s), Types of publication
			Two dimension video analyses was captured at 60 Hz. and analyzed with Ariel Performance Analysis System (APAS). Dominant and non-dominant lower limb joint kinematics were analyzed.	88.9˚±13.3˚ Knee joint angular velocity between dominant and non-dominant leg were significantly different. - Right double collar 22.9˚/sec ±185.1˚/sec - Right double under hook 44.8˚/sec ±111.2˚/sec - Left double collar 115.6˚/sec ±141.6˚/sec - Left double under hook 124.8˚/sec ±125.6˚/sec Joint angle and angular velocity of left and right knee between both clinching were significantly correlated	
8.	Myers *et al*. 2013 [1]	n = 32 (16 Thai Muay Thai fighters, 20.75±1.98 yrs; 54.97±4.6 kg, and 16 UK Muay Thai fighters; 24.38±3.67 yrs, 63.38±5.09 kg)	- The winners were analyzed by computerized notational system. - Three multilevel Poisson regression models were used to estimate differences in technique frequency and key performance indicators between Thai and UK fighters.	- Thai fighters used more attacking and defensive techniques than UK fighters (knee and round kicks to the body and push kicks. - Thai fighters tended to catch an opponent's leg more often than UK fighters. - UK fighters more likely to use other defensive techniques - Interaction effect between nationality and a range of quality indicators (delivering techniques at an appropriate distance; effectiveness of techniques used and returning to a balanced stance) were significantly different.	Sports Biomechanics.
9.	Trial & Wu, 2014 [13]	n = 10 (23±5 yrs; 1.8±0.1 m; 73.3±11.4 kg; 5.9±5.4 yrs of experience)	- Simulating double collar-tie and double underhook clinching positions. - Joint reflective markers were placed on the right side for video analysis. - Six continuous knee strikes with dominant leg in each of 2 clinching positions. - Two dimensional video analysis was used with APAS software.	- Hip joint angular displacement between double collar-tie (103.2˚±13.4˚) and double underhook (88.4˚±12.4˚) was significantly different. - Both clinching positions were strongly correlated in the hip angular velocity and acceleration.	Sports Biomechanics.
10.	Del Vecchio, Silva, & Farias, 2015 [14]		- Observational analytical study - 65 matches in a Brazilian championship were recorded by in *loco* recording and analyzed by Kinovea. - Observation, Preparation, and Interaction periods and High Intensity (HI) and Low Intensity (LI) ratio were studied. - The average duration of the rounds between competitive phases was compared. - A generalized linear model was	- Observation period was 7 to 8 sec. - Preparation period was near 3 sec. - Interaction period was 4 to 4.5 sec. - The interaction between preliminary (5.5±0.3 sec) and finals (3.7±0.5 sec) were significantly different. - Pooling the Observation and Preparation time as LI and Interaction as HI. The HI:LI	Sports Biomechanics.

No.	Authors, Publication year [refs]	Number of participants, Age range, Height and weight, Experience level	Study design	Outcomes/Conclusions	Classification, Inclusion reason(s), Types of publication
			applied considering effort duration as a dependent variable and competitive level, round, and effort type as independent variables.	ratios were 1:2 in eliminatory and 1:3 in final matches.	
11.	Myers, Nevill, & Al-Nakeeb, 2012 [15]	n = 10 experienced Muay Thai judges (n = 7 UK; n = 3 Thailand)	Experimental. A counterbalanced repeated measure design was used, with the judges being randomly allocated to either a noise condition first, followed by a no crowd noise condition, or vice versa.	Crowd noise increased the scores of Muay Thai judges, resulting in an advantage to the home competitor.	Sports Psychology. Fulfils criteria. Original research article.
12.	Da Silva, Ishiikawa, & Nessi, 2015 [16]	n = 3 elite Muay Thai athletes, age between 20 - 45 years old, male and female.	Experimental massage interventions pre and post competitions. Adopted evaluation sheets used to assess psychological and physical feelings post massage interventions.	Anti-stress massage performed 15 min before training and 30 min after training, with the goal of relaxation, was effective in decreasing perceived muscle soreness, increased feelings of wellbeing, increased relaxation after massage, decreased stress, and increased sense of well being. Reduced PMS symptoms in females.	Sports Psychology. Fulfils criteria. Original research article.
13.	Ong & Wan Ruzmin, 2015 [17]	n = 120 (male and female), untrained, recreationally participate in Muay Thai activity.	Survey questionnaires given to participants of Muay Thai activities conducted at 4 Muay Thai gym located in Klang Valley, Kuala Lumpur.	- Both genders of Muay Thai participants were highly motivated by existence related factors (physical fitness and self defence). - Second ranked motivation factor for male practitioners was growth related factor. - Second ranked motivation factor for female was relatedness.	Sports Psychology No full text although fulfil other criteria. Conference abstract.

Strength and conditioning training for Muay Thai

A review article by Turner, 2009 [5] provides quite a comprehensive suggestion on strength and conditioning applications for Muay Thai athlete. However, the suggestions were made based on the research findings of other types of combat sports, and not based on studies conducted specifically for Muay Thai research purposes. While there are several other combat sports that may share several similar fighting techniques with Muay Thai, as a whole, various differences exist. Muay Thai involves 8 impact contacts during a match, while sports cited as being quite similar to it have a much lower number of impact contact point (such as boxing, with 2 impact contacts, and taekwondo, with 4 impact contacts). With all upper and lower limbs actively involved in attacking or defending movements, different biomechanical and physiological stimulus and adaptations may be experienced by a Muay Thai master. As indicated by the author [5], for any implementation of strength and conditioning interventions, the starting point will always be the execution of needs analysis in order to identify all physiological and biomechanical requirements of the sports. While this is true, typical problems in exercise programming set ups are the availability of actual base data or research on each specific sport (i.e., Muay Thai). With Muay Thai, research-based data is nearly non-existent. The author [5] has done excellent work by finding studies on near similar types of sports, sufficient for the time being while awaiting more original research in Muay Thai to emerge. Nevertheless, actual studies on Muay Thai are needed in order to provide more accurate baseline assessments prior to the development of any strength and conditioning programs for Muay Thai athletes.

Physiological-based research on Muay Thai

At about the same time as the review publication discussed earlier [5], an original research work on Muay Thai was published, showing probably one of the first actual physiological profiles of Muay Thai athletes [6]. The study recruited 10 skilled, well trained, and regularly competing male Muay Thai athletes. A simulation match was performed, with participants wearing a portable gas analyzer, providing data on oxygen uptake, carbon dioxide production, and heart rate responses during the match. Their results indicated high involvement of both aerobic metabolism and anaerobic glycolysis [6]. As indicated in their discussions, 2 notable limitations of the study were the simulation method (rather than actual matches) and the number of participants involved. While appropriate justifications has been given, which provide evidence that neither limitation affected the findings, an increased number of participants and, if possible, a virtual simulation (which may provide an environment of 2 persons fighting, rather than a single individual) is suggested for similar studies in the future. Another concern was that, out of 10 participants, 6 were competing at the international level, whereas another 4 only competed at the national level. Thus, the level of physical capabilities (skills mechanics, aerobic power) may differ greatly, as shown in other sports studies comparing elite (international level) and non-elite level athletes [18,19].

Another study by Cappai *et al*. [7], published 3 years later, investigated Muay Thai athlete blood lactate and heart rate response during real matches, with match analysis. In their study, a preliminary incremental exercise test for anaerobic threshold and maximal oxygen consumption determination was done around 3 days prior to the matches. Match analyses performed indicated that, for the duration of 120 sec in each round, Muay Thai athletes were in an active phase (attacking) for about 67.9 % of the time, and about another 39.9 % of the time in a passive phase (studying and preparing for the next move, or passive defense) [7].Their study also found that heart rate responses for the same matches were at an average of 178.9 ± 0.3 bpm, which was above the anaerobic threshold assessed earlier. As predicted, their findings also indicated that blood lactate increased significantly from round 1 to round 4, with maximum blood lactate recorded at12.55 ± 1.1 mmol.L and at an average of 9.72 ± 0.6 mmol.L. The researchers [7] then used the match analysis and blood lactate data for comparison between winners and losers, in which no significant differences were found in terms of blood lactate accumulation or technique application (time spend in active vs passive phases). The similarity found between losers and winners raise more questions than it gives answers. It is akin to both opponents using similar metabolic efforts and strategies, yet one of them will win the match. Thus, as indicated by the researchers, more studies are needed in order to better understand Muay Thai matches and athletes.

Our search also found 2 studies that have been done on body composition and nutritional based assessment. For the purpose of this review, both nutritional related studies were placed under the sports physiology classification.

Rossi and Oliveira [8] assessed anthropometry profiles, hydration status, and dietary intake profiles of Brazillian Muay Thai practitioners. In comparison with other studies, body height and body weight in their study did not very much differ with other studies reviewed previously. However, the separation of participants that were measured for anthropometry and dehydration status (n = 10) from participants assessed for dietary intake (n = 20) might have reduced the impact of the statistical analysis performed. The age, body height, and body weight of participants assessed for dietary intake were unable to be verified, except that all participants were aged above 18 years old [8]. This jeopardized the use of data presented in any further comparisons or analyses in the future. Findings which also indicated lack of protein and micro nutrients indicated that any physical conditioning program prescribed may have much better results if this insufficient nutrient intake is solved and rectified. Again, this study shows how important profiling assessment is, so that exercise or training prescription can be done properly.

Another interesting study was done by Krick and Raschka [9], in which they compared body compositions of male Muay Thai fighters with male students majoring in physical education. It can be assumed that students majoring in physical education typically participated in various types of sports. Thus, comparisons made might also indicate the nature or body build of Muay Thai fighters in comparison with other recreationally active people. However, based on the location of the authors [9], an assumption can be made that the students had a mainly European body build (average body height 184.1 cm), where Europeans tend to be much taller than the normal Asian body build/height [20]. A study

has indicated that Thai adults in both genders had significantly smaller body girths than UK adults after adjusting for age and height [21]. This is worth noting, as Muay Thai is mainly practiced and is more highly popular in Thailand compared to other countries. The findings on the other hand indicated that the Muay Thai fighters had a much smaller body build (average 177.2 cm height) in comparison to the students majoring in physical education.

Biomechanical based research on Muay Thai

Proper technique execution is important in any combat sport match. Skill execution can be said to be dependent on appropriate muscle activation, where body movement joint angle and positioning determines the effectiveness and efficiency of the skills that are intended to be performed. In developing a proper strength and conditioning program, the biomechanics background of all movements involved within the sport needs to be clearly identified and calculated. Muay Thai movement characteristics definitely differ from Taekwondo or other combat sports, no matter how similar they look from normal viewing. As evidently shown earlier [7], Muay Thai opponents spend about 39.9 % of their in the ring time on a passive preparation phase. In any combat sport, the preparatory phase typically means that the opponents will still be on high alert and be positioned to promote readiness to react. The assumption that can be made is that this ready position is also influenced by the movement characteristics of the sport (defensive technique, impact points of contact available to be executed, etc.). Muay Thai has more contact points than most other combat sports, and attacks using knees and elbows may be fatal (knock-out); their ready positions may be different in actual match competitions. Fighters may not want to spend time studying each other's movements, as that may also give time to the opponent to attack using the highly dangerous elbow and knee hits. Thus, their passive preparation phase may actually be more active, and involve more muscles being activated, compared to other combat sports, during both the passive and active phases. However, at the time of this write-up, no previous studies had been able to verify all of these assumptions.

From the search performed, 6 studies met the inclusion criteria for the classification of the sports biomechanics area of study in Muay Thai (**Table 1**).

Psychological research on Muay Thai

Three studies were found related to the area of sports psychology (**Table 1**). However, all 3 publications had not presented all of their important information appropriately (i.e., age of participants in survey etc). The number of participants used was also very low in one study (n-3), with details on age, weight, and height in accordance to gender and methodology used not being clearly stated in details to allow replications or future comparisons [16]. Similar flaws can be observed in the other 2 studies [15,17]. The original research article by Myers *et al*. [15], however, did not examine the athletes, but assessed the decision making process and psychological effects of crowds on judge decisions. This at least provides further research-based findings which can be used to assist improvement in the sport of Muay Thai.

Studies in areas outside of Sports Science

Eighteen studies were classified as studies in areas outside of Sports Science [22-39]. While studies classed under this classification are not discussed in detail in this paper, it is important to note them. It indicates that, apart from sports science, studies in other areas in relation to Muay Thai are also lacking. Out of 18 publications, 10 were in the field of sports medicine/sports injuries [22-30], with most of them published in high impact journals. Thus, the quality of research related to sports medicine is much higher than most other publications in the area of sports science or other related areas of study.

Conclusions

Based on the systematic review performed, it can be concluded that there was not enough research found on the sport of Muay Thai. The lack of baseline and background data makes it difficult for sports scientists and practitioners alike (coaches, athletes, managers, etc.) to develop a systematic training and

monitoring plan for Muay Thai athletes. Even in other area of studies, with basic studies also lacking, it will be hard to impose new ideas or develop the sport to a higher quality, especially for the benefit of its practitioners.

Altogether, it is also worth noting that no sports science-based studies have been performed on female Muay Thai athletes or practitioners, although their participation and competitions exist.

For future studies in the area of sports science, several recommendations are suggested:

a) Quality physiological, biomechanical, and psychological based profiling and comparison studies are needed, with research participants including both elite athletes and amateurs. as well as recreationally active participants.

b) Exercise programming or intervention studies that focus on preparing Muay Thai athletes for better performance and lessening the risk of injuries are needed. This can be considered as testing various types of training programs on Muay Thai athletes, enabling practitioners in the future to properly select exercise and training programs that suit their needs and levels of participation.

c) Studies to be done should be planned properly, and use equipment or materials that can be said to reach the 'gold standard' of output (high reliability and validity).

d) The quality of publication of results should be improved, as quality publications ensure the continuity of the research and ability of practitioners and scientist alike to adapt/adopt the findings.

e) Research made should be highly focused on the sport of Muay Thai (i.e., use of proper Muay Thai techniques, participants etc.); comparison studies with other combat sport participants would also be interesting.

In conclusion, with the increased popularity and growing interest in Muay Thai as a competitive sport and for recreational purposes, more sports science studies will ensure the sport of Muay Thai evolves and moves forward, with the support of scientific evidence.

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