The role of strength on punch impact force in boxing

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The Role of Strength on Punch Impact Force in Boxing
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Abstract:	The ability to punch with a high impact force is beneficial to boxers as there is an increased likelihood of success. Punch impact force differentiates between performance level, weight class, gender and punch type in competitive boxers. Whilst technique is likely to play a major role in punch impact force, the capabilities of the neuromuscular system may also be a limiting factor. This review examines the role of strength on punch impact forces in amateur and professional boxers. The maximal-strength qualities of the lower-body, as well as explosive-strength qualities of both the upper- and lower-body, are largely associated with punch impact force in elite amateur boxers. Specifically, elite amateur boxers who punch with 'high' impact forces have greater levels of lower-body maximal-strength and explosive-strength when compared to elite amateurs who punch with 'low' impact forces. However, the maximal-strength capabilities of the upper-body are not associated with punch impact force and does not differentiate between elite boxers who punch with 'high' and 'low' impact forces. Therefore, based off the present evidence, this review recommends that for boxers who aim to develop their punch impact force, it may be advantageous to emphasise both maximal- and explosive-strength development of the legs, with only an explosive-strength focus in the upper body. However, it is important to highlight that, to date, there are a lack of experimental studies in both elite amateur and professional boxing. Further, there is a dearth of research in female boxing. Future experimental studies are needed to infer causality regarding the role that strength training has on punch impact force in both elite amateur and professional boxers.
Response to Reviewers:	Reviewer #1 General Comments: The study is interesting and provides valuable information to practitioners and sport scientists. However, there are important aspects of the manuscript that should be improved. In some parts of the manuscript, authors deviated from the study subject, and in contrast, some important aspects of the outcomes analyzed could be better emphasized. In general, the tables and main results of the analyzed studies were well presented. In addition, the study was designed in a logical and concise sequence according to the defined purpose. Below the authors can find comments and questions about specific parts of the manuscript.

We just want to acknowledge this great review. Your feedback has been excellent and has added a lot of value. Kindest regards.

Abstract
The abstract section was well designed and provided a good idea of the manuscript. One point of concern is that the authors were very assertive in relation to the main outcomes analyzed during the review. However, considering that this is a narrative review without a systematic search and analysis of data, maybe the recommendations about the main outcomes analyzed could be less emphatic, since there is a limited body of evidence analyzing "causality" between upper- and lower-body strength and punching impact.

Many thanks for your Abstract recommendations. We have tried to address your points to make the Abstract less assertive and emphatic regarding the paper's recommendations based off the limited body of evidence on the subject. We have added:
-"Therefore, based off the present evidence, this review recommends.."
-"However, it is important to highlight that, to date, there are a lack of experimental studies in both elite amateur and professional boxing."
-"Future experimental studies are needed to infer causality regarding the role that strength training…"

Introduction
"The cardiovascular characteristics of elite boxers (44) and the demands of simulated competition (i.e. Vo2 max, heart rate, blood lactate) (13,18) have been reported, however, there is a lack of research investigating the role of the neuromuscular system (i.e. muscular strength) on punch impact forces in boxers." To support this statement, authors cited two studies performed during simulated combat and one about the physical characteristics of boxing athletes. Although these studies can give readers a good idea of the importance of the cardiovascular characteristics of boxers, the rationale here should be improved. In addition, authors could improve this part by better describing these studies or other similar works, emphasizing that this knowledge is well comprehended in the literature.

Many thanks for your comments. We have included changes and extra citations to emphasise that, compared to the neuromuscular system, the importance of the cardiovascular system is well-established in the literature.
-"The importance of the cardiovascular system (i.e. VO2max) for elite boxing has been well established in the literature (13, 18, 44). However, in comparison, there has been a lack of research investigating the role of the neuromuscular system (i.e. muscular strength) on punch impact forces in boxers."

"Whilst technique is likely to play a major role in a boxer's punching ability, the force production capabilities of the neuromuscular system may also be a limiting factor (i.e. peak force, rate of force development [RFD])." This is the main rationale of the study and should be better developed. Some references are necessary to support this statement as well as a more detailed description of studies, emphasizing the importance of neuromuscular abilities for punching impact.

Thank you for your suggestion here. We have tried to improve our rationale of the study by adding in specific references into the Introduction to emphasise the potential importance of the neuromuscular system for punching:
-"Whilst technique is likely to play a major role in a boxer's punching ability, recent research suggests that the force production capabilities of the neuromuscular system may also be a limiting factor (i.e. peak force, rate of force development [RFD] etc) (12,27,36)."

"Given the complexity of the physical training process for both amateur and professional boxers (e.g. calorific deficit, weight-loss, sparring, conditioning, pad work etc) (39,40), trainers and support staff would benefit from evidence-based guidance regarding the efficacy of strength training on improving the neuromuscular system and therefore punch impact force." Indeed, these factors are very important, but it is necessary to better elaborate the interferences of these variables on the strength and power development, for example, by describing how weight-loss strategies can interfere in the strength training responses.

Thanks for the advice here. We have added in:
-"Further, limited research suggests that, in an effort to "make weight" for a fight (e.g. calorie deficit and potential compromise in muscle mass), boxers may potentially reduce the function of their neuromuscular system (i.e. RFD) and therefore punch impact force (18). However, strength training may reduce the detrimental effect of weight loss strategies on punching ability."

Methods

"This is a brief review and as such does not need to obtain ethics approval." This sentence is not necessary.
We have removed this sentence.

The methods section could be better described. Although this is a brief review, if authors performed the search for studies using a defined strategy, more information could be given. What variables were obtained? Was the age of the participants considered?

We added in:
-"The following information was extracted from each of the selected studies: study information (i.e., author(s), year); descriptive information of participants (i.e., performance level, gender, age, body mass); punch assessment (i.e. punch type, punch variable, punch measurement tool & protocol), maximum-strength assessment (i.e. assessment type, variables), explosive-strength assessment (i.e. assessment type, variables), relationships between strength and punch impact force (i.e. Pearson's r), and strength training interventions (i.e. strength quality type, training phase, duration, frequency, control group, performance measures, results)."

Results
Page 5, Lines 42-43 - Page 6 Lines 14-15: This information is very interesting; however, it is a bit beyond the study purposes and is focused on a very particular point around the punching force impact measurement. The discussion before this part already provides a good idea of the problems related to the assessment of this variable.

Many thanks for this recommendation. We have removed the section from Page 5 (Lines 42-43) to Page 6 (Lines 14-15).

Page 6, lines 20-48: This information is very relevant and based on considerable practical experience. In a scientific context, it is recognized that the results of physical tests are not the same as performing an actual sport-specific action. Authors could reduce this part and emphasize the importance of performing these assessments and the importance of using reliable tests.

We have reduced this section and have emphasised the importance of using reliable tests.

"The straight right, also known as a 'cross,' is traditionally thought to be a more 'damaging' punch than the jab. The larger punch impact force of a cross is most likely due to the punch involving a greater impulse (or 'drive') of the rear leg and subsequent rotational force production of the hips." References are necessary here.

We have now cited these references to support our statement:
-Lenetsky, S, Brughelli, M, Nates, RJ, Neville, JG, Cross, MR, and Lormier, AV. Defining the Phases of Boxing Punches: A Mixed-Method Approach. The Journal of Strength & Conditioning Research 34: 1040–1051, 2020.
-Filimonov, VI, Koptsev, KN, Husyanov, ZM, and Nazarov, SS. Boxing: Means of increasing strength of the punch. Strength & Conditioning Journal 7: 65–66, 1985.
-Smith, MS, Dyson, RJ, Hale, T, and Janaway, L. Development of a boxing dynamometer and its punch force discrimination efficacy. Journal of Sports Sciences 18: 445–450, 2000.

"However, due to this specific motion of the uppercut (i.e. upward movement and impact), and as dynamometers are generally constructed for punches that are thrown horizontal to the ground (i.e. straights and hooks). there is a lack of research on the punch." Maybe the end of this sentence might be changed to: "there is a lack of research analyzing the characteristics of this punching technique."

Thank you for the recommendation of this addition. We have added in "…the ground (i.e. straights and hooks), there is a lack of research of this punching technique."

"Maximal-strength", Pages 8 and 9: Most of the discussion presented here is a bit out of the study purposes. The importance of comparing maximal-strength values of boxing athletes with athletes from other sports is not clear. It is important to focus on the main study subject (e.g., the importance of strength to punching force impact).

Many thanks for your comments. We have now removed some sentences from this section. Whilst we appreciate that this section may seem slightly out of context with the specific research question, we feel that it is important to explain to the reader the maximal-strength levels of boxers compared to other sports. By including this section, practitioners are able to compare the neuromuscular capabilities (and therefore the potential window of improvement / adaptation) of boxers to other sports.

"Additionally, substantial evidence demonstrates a strong association between CMJ height and athletic tasks such as sprinting (31) and change of direction (49)." This information is not necessary here.

We have removed this sentence.

Page 10, lines 22-52: Same comment as before, the importance of comparing the CMJ height between boxers and athletes from other sports to the present study purposes is not clear.

Many thanks for the feedback on this. As we mentioned previously, whilst we appreciate that this section may seem slightly out of context with the specific research question, we feel that it is important to explain to the reader the explosive-strength levels of boxers compared to other sports. By including this section, practitioners are able to compare the neuromuscular capabilities (and therefore the potential window of improvement / adaptation) of boxers to other sports.

Page 12: "Previously, researchers have primarily focused on the resultant punch impact force characteristics of elite boxers, with fewer studies investigating the contributing role of force production from the lower- and upper-body." Please provide references to support this statement.

Thank you for highlighting this. We have added in references to support the statement.

"Additionally, identical associations were found between absolute maximal-strength and other punch impact variables such as impulse (r = 0.68) and force at 5ms (r = 0.68). Interestingly, relative peak force of the lower body (i.e. IMTP peak force normalised to body mass) was not significantly related to punch impact force. Consequently, boxers' larger body mass (and lean tissue) may somewhat partially explain their great absolute maximal strength, and therefore larger punch impact force." If this information is related to the study of Dunn et al., it would be good to cite the study again at the end of the sentence.

Thanks – we have moved this sentence slightly (to improve flow) and cited Dunn et al. "Interestingly, Dunn et al (15) found that relative peak force of the lower body (i.e. IMTP peak force normalised to body mass) was not significantly related to punch impact force."
"Moreover, the association between body mass and punch impact force in boxers has been previously reported in the literature (30,45,53)."

Authors initiated a discussion about the relationship between "body-mass" and punching impact, but the following sentence is about the relationship between peak force in isometric squat and punching impact. Please, correct this.

Thanks – to improve flow of reading, we have moved this sentence to the start of this section:
"Additionally, identical associations were found between absolute maximal-strength and other punch impact variables such as impulse (r = 0.68) and force at 5ms (r = 0.68). Supporting this, Loturco et al (30) found that absolute peak force, measured through an isometric squat, was largely associated with both jab (r = 0.79) and cross (r = 0.73) impact force in elite male and female amateur boxers."

"However, IBP peak force was strongly correlated with relative punch impact force (r = 0.62)." From which study is this information? Please, cite the reference here.

We have added in the citation here.

Page 14: Authors suggest including table 4 here, but there is no mention of this table in the above paragraphs. Why is this table important here? What information does it provide?

We forgot to refer to Table 4 in this section. We have added in "…IBP peak force in elite male amateur boxers was not related to punch impact force, impulse or force at 5ms (see Table 4)."

"Additionally, CMJ peak force and peak power were also positively correlated to other punch variables such as impulse and force at 5 ms (r = 0.51 to 0.66)." Please, provide a reference here.

We have now provided a citation for this sentence.

"Therefore, the present literature demonstrates that punch impact force is more related to the 'ballistic' qualities of the upper-body (i.e., bench throw) rather than peak force or maximal-strength capabilities (i.e., isometric bench press [IBP])." Please, cite the studies here.
We have now provided citations to support this statement.

"Strength Characteristics of Low, Medium and High Punch Impact Force Boxers" This section is a bit difficult to follow, especially the discussion about the influence of "body-mass" on the outcomes discussed.

We have tried to improve our discussion on 'body-mass' to increase the understanding in this paragraph: "Nevertheless it is important to highlight that the 'high' punch impact force group's body mass was significantly larger than the 'low' group. This larger body mass may potentially explain the greater levels of lower-body absolute maximal-strength (i.e. more muscle mass) and larger punch impact force (i.e. greater momentum) (40)."

Page 17, lines 35-52: Authors properly highlighted that correlation does not imply in causality. Accordingly, it is important to include longitudinal studies analyzing training effects in this review.

Many thanks for this comment. We have replaced this paragraph and included a brief section here titled "Strength Training Interventions in Elite Boxing"
-"It is important to note that there has been a lack of experimental research investigating the effect of strength training on punch performance in boxers. However, there has been several observational studies published in elite amateur populations over the course of a microcycle (32), mesocycle (7,8) and macrocycle (25) (see Table 7). However the ability to infer from these findings is limited due to the lack of control groups, standardised protocols and valid punch force dynomometry. Therefore, future experimental studies utilising scientifically rigorous methods are needed to clarify the role that strength training has on punch impact force in both elite amateur and professional boxers."

"In elite boxers, punch impact force differentiates between performance level, weight class, gender and punch type." Please provide a reference here. This information should be better explored across the study. Especially in the "Punch Type, Performance Level, Gender & Weight Class" section, in which authors mostly highlighted the differences among the distinct punching techniques.

We have now provided references for this statement. Regarding the information being better explored, we focused mainly on punching type due to (i) the majority of the literature investigated the effect of punch type on punch impact force, and (ii) we feel that this information is more useful for the practitioner re: punch biomechanics and strength programming for increasing punch impact force (i.e. special-strength training for jab vs. cross vs. hook). Further, for more details on "performance level, weight class, gender," the reader is now directed in this section to "(see Table 1 for more details)"

Page 19: "Given the complex and physically demanding training process in both amateur and professional boxing, such as weight loss (e.g. calorific deficit, weigh-ins)." Please avoid repetition. This information is already highlighted in other parts of the manuscript.

Thanks for highlighting this. We have removed this part of the sentence and shortened this paragraph considerably.

The first sentence of the "practical implications" section (which should be "practical applications" in the JSCR) is too long and difficult to follow. This section should be shortened to focus on the main practical aspects analyzed in the selected studies. After analyzing the literature on the main subject investigation, what message can be provided to practitioners? This is not clear.

Thank you for your comments. We have reduced the length of this section. However, we feel that based on the current evidence, we have provided practitioners with comprehensive recommendations on how to improve strength and punch impact force in boxers. Further, to improve the reader's understanding, we have added in sub-headings for "Maximal-Strength," "Explosive-Strength," and "Special-Strength."

Reviewer #2: General Comments:
The paper reviews literature that examines punch force and muscular strength characteristics in elite boxers. The paper gives a thorough overview of the findings of previous literature, and provides detailed practical recommendations for strength and conditioning staff. The paper is very well written and conveys its findings well. My commendations to the authors.

We just want to acknowledge this great review. Your feedback has been excellent and has added a lot of value. Kindest regards.

Specific Comments:
Introduction
Page 3, Line 5: With amateurs adopting the 10-point-must system is it relevant to list scoring a point as an aim of boxing anymore? Understandably, some of the papers reviewed may have been conducted during the time when point scoring systems were in place, but I don't believe this is the case anymore and given the outcome of bouts is not discussed any more specifically I would suggest this point is now void.
Many thanks for bringing this to our attention. We have now removed any reference to scoring a point in the manuscript.

Line 25: (i.e. VO2max - it looks like the 'O' is actually a zero... it might be the font, but please double check this is an O, not a 0 (zero)). In the same sentence, please add

	'concentration' to blood lactate, if this is indeed the measurement you are referring to. Thank you for highlighting this. We actually removed parts of this sentence (and therefore blood lactate), but we have kept VO2max. The 'O' in VO2max looks like a zero due to the font. Methods Page 4, Line 13-23: again, it may be the font that looks strange, but it appears that there is a combination of double quotation marks ", and two single quotation marks '' in use. Please double check and keep consistent. We have double-checked the quotation marks and removed any errors – thank you for spotting this! Line 40-42: The last sentence sticks out a little bit. If this is required wording by the journal then keep it as it is, but otherwise I would suggest to rewrite it in past tense to match the rest of the paragraph. We have now removed this sentence from the Methods section. Results - Impact force: Page 6, line 12-15: The last sentence referring to Lenetsky et al (28) also sticks out a little. Consider reworking this sentence into the paragraph to improve readability Thanks for the advice - to improve the readability of the Results section we have decided to remove the final 5 sentences of this paragraph. Page 7, line 5-14: It is best to refrain from using left and right when referring to punches (especially when a stance hasn't been specified). When referring to the cross in line 12-14, I would suggest using straight rear hand, or similar to include southpaws too. Thank you for highlighting this point. We have now replaced "straight right" with now "straight rear hand" Line 34-37: I believe the Walilko et al paper goes into some detail regarding rotational acceleration of the head. It may be an appropriate reference here. Thank you for this. Yes, Walilko et al highlights the importance of rotational acceleration of the head for punch severity. We have now cited Walilko et al in this sentence. Strength Characteristics of Boxers: Page 10, line 41: The suffix -ka for martial artists is limited to the Japanese martial arts (Judo and Karate in this case). I believe proponents of Taekwondo are called Taekwondo players. Taekwondo practitioners, or Taekwondo athletes are also options. Many thanks for this – we have now changed to "taekwondo players" Line 41: Judo is listed twice. We have removed the 2nd 'judo' General for this section: The final conclusion certainly has merit and is worth discussion. Something to consider - There is certainly the 'traditional' mindset within boxing, but is it to such a great extent that there is a noticeable difference in EUR between boxers and the other combat sports that have been listed here, which also suffer from this traditional mindset? Is it also possible that the difference between boxers and other martial artists is somewhat to do with the specific demands of the sport? Olympic karate and taekwondo athletes certainly 'bounce' a lot, I would think more than boxers who tend to be somewhat more grounded. Additionally, judoka and wrestlers frequently take some, if not all of the weight of their opponent, and still complete powerful and technical moves. Consider also discussing these differences. Many thanks for these very insightful points. We have now included in this section: "boxers have a lower explosive-strength ability due to (i) the specific physical demands of the sport" The Relationship between strength characteristics and punch force characteristics

	Page 12, line 8: 'lack of evidence investigating' strictly speaking, evidence is the results of an investigation, so evidence can't investigate. You could write 'lack of research investigating' or something similar to improve the readability. Thank you for highlighting this – we have now replaced this with 'lack of research.' Line 42: In reference to Filimonov et al. There is another paper on this topic which might be worth considering for inclusion (Kinematic and kinetic analysis of throwing a straight punch: the role of trunk rotation in delivering a powerful straight punch) Many thanks for this suggestion. We have added in: "Recent work also supports this view, suggesting that trunk rotation bridges the legs to the upper body, allowing the legs to transform vertical GRF to horizontal punch impact force (44)." Page 15, line 12: in most ranges presented on this page (r = x - y) format is used. Please update (r = 0.51 to 0.66) to also reflect this format and remain consistent We have now changed this. Line 12: Technically the Loturco paper came before the Dunn paper Thanks for spotting this. We have now moved this around, mentioning Loturco's work before Dunn's: "In elite male and female amateur male boxers, Loturco et al (25) found strong relationships between CMJ height and both jab (r = 0.72) and cross (r = 0.80) punch impact forces. Furthermore, strong associations were found between punch impact force and other lower-body explosive-strength exercises such as the squat jump (r = 0.77 – 0.78) and the loaded jump squat (r = 0.83 – 0.85). Supporting work from, Dunn et al (12) observed…" Lines 51+: Linking the effective mass literature into this paragraph could be smoother. I suggest to rewrite to improve the readability. All of the relevant information is there, but I believe a re-write could help readers. Many thanks for your advice here. We re-written this section to try and improve the readability: "Immediately before the impact of a punch, some researchers suggest that there is a second pulse of muscular activation that causes the arm, chest and torso to 'stiffen,' creating a larger punch impulse (i.e. effective mass). (27,34). The effective mass concept proposes that the upper body may have an important role in instantaneous force production prior to the impact of a punch (i.e. the 'second pulse'). Therefore, this highlights the importance of a boxer's upper-body explosive-strength qualities (i.e. RFD), rather than their upper-body maximal-strength qualities (i.e. peak force), during the delivery of a punch." Page 17, line 45: Yes, there is a dire need for research on female boxers. Consider adding this to the abstract where the same is said for professional boxers. Thanks for pointing this out. We have added this sentence into the Abstract: "Further, there is a dearth of research in female boxing."

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14th December 2021

JSCR Re-Submission Cover Letter Re: *The Role of Strength on Punch Impact Force in Boxing*

Dear Editor,

Please find attached the re-submission of our manuscript entitled "*The Role of Strength on Punch Impact Force in Boxing*." This manuscript is original and not previously published in any form including on preprint servers, nor is it being considered elsewhere until a decision is made as to its acceptability by the JSCR Editorial Review Board.

We just want to acknowledge the great review from the JSCR reviewers. The reviewers feedback has been excellent and has added a lot of value.

Yours Sincerely,

Kris Beattie, Alan Ruddock

The Role of Strength on Punch Impact Force in Boxing

Running head: Strength & Punch Force in Boxing

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The authors have no conflicts of interest that are directly relevant to the content of this article. The results of this present study do not constitute endorsement of the product by the authors or the NSCA.

The Role of Strength on Punch Impact Force in Boxing

ABSTRACT

The ability to punch with a high impact force is beneficial to boxers as there is an increased likelihood of success. Punch impact force differentiates between performance level, weight class, gender and punch type in competitive boxers. Whilst technique is likely to play a major role in punch impact force, the capabilities of the neuromuscular system may also be a limiting factor. This review examines the role of strength on punch impact forces in amateur and professional boxers. The maximal-strength qualities of the lower-body, as well as explosive-strength qualities of both the upper- and lower-body, are largely associated with punch impact force in elite amateur boxers. Specifically, elite amateur boxers who punch with 'high' impact forces have greater levels of lower-body maximal-strength and explosive-strength when compared to elite amateurs who punch with 'low' impact forces. However, the maximal-strength capabilities of the upper-body are not associated with punch impact force and does not differentiate between elite boxers who punch with 'high' and 'low' impact forces. Therefore, based off the present evidence, this review recommends that for boxers who aim to develop their punch impact force, it may be advantageous to emphasise both maximal- and explosive-strength development of the legs, with only an explosive-strength focus in the upper body. However, it is important to highlight that, to date, there are a lack of experimental studies in both elite amateur and professional boxing. Further, there is a dearth of research in female boxing. Future experimental studies are needed to infer causality regarding the role that strength training has on punch impact force in both elite amateur and professional boxers.

Key Words: boxing, punch impact force, maximal-strength, explosive-strength, special-strength

INTRODUCTION

The main aim of boxing is to succeed in delivering a clean punch to the opponent without being punched in return (i.e. control the bout, knock-down or knock-out the opponent) (21). Punching (e.g. jab, cross, hook, uppercut) is a rapid whole-body and multi-planar muscular movement that accelerates the fist towards the opponent's head or torso (11). The ability to punch with a high impact force is beneficial to boxers as there is an increased likelihood of success through influencing the judges' perception of a clean punch, impairing the fighting ability of the opponent, knock down or knock out (13,41). To succeed in delivering precise and forceful punches over the course of a bout, boxers require a well-developed cardiovascular and neuromuscular system. The importance of the cardiovascular system (i.e. $\dot{V}O_{2max}$) for elite boxing has been well established in the literature (10,14,40). However, in comparison, there has been a lack of research investigating the role of the neuromuscular system (i.e. muscular strength) on punch impact forces in boxers. Whilst technique is likely to play a major role in a boxer's punching ability, recent research suggests that the force production capabilities of the neuromuscular system may also be a limiting factor (i.e. peak force, rate of force development [RFD] etc) (12,27,36). Given the complexity of the physical training process for both amateur and professional boxers (e.g. calorific deficit, weight-loss, sparring, conditioning, pad work etc) (35,36), trainers and support staff would benefit from evidence-based guidance regarding the efficacy of strength training on improving the neuromuscular system and potentially punch impact force. Further, limited research suggests that, in an effort to "make weight" for a fight (e.g. calorie deficit and potential compromise in muscle mass), boxers may potentially reduce the function of their neuromuscular system (i.e. RFD) and therefore punch impact force (18). However, strength training may reduce the detrimental effect of weight loss strategies on punching ability. Therefore, the purpose of this critical review is to examine the role of strength on punch impact forces in amateur and professional boxers.

METHODS

This narrative review critically examines the role of muscular strength on various factors associated with punch impact force utilising cross-sectional, correlational, and observational studies. A search was performed using the MEDLINE, Google Scholar, Scopus, SPORTDiscus and Web of Science search engines (up to July 2021) for English-language, peer-reviewed articles. The search strategy and key words used were as follows: "boxing," "boxing AND strength," "boxing AND neuromuscular system," "boxing AND weight training," "boxing AND resistance training," "boxing AND punch performance," "boxing AND punch impact force," "boxing AND peak force," "boxing AND power," and "boxing AND anaerobic." An initial selection was performed by reading the titles and abstracts to assess the relevance of articles. Articles were excluded if the full text was not available, if participants did not include competitive boxers, or if strength or punch performance was not assessed. Due to the narrative nature of this review, references from the original studies were searched for further relevant investigations. Data from the selected studies were then extracted by the lead author (KB). The following information was extracted from each of the selected studies: study information (i.e., author(s), year); descriptive information of participants (i.e., performance level, gender, age, body mass); punch assessment (i.e. punch type, punch variable, punch measurement tool & protocol), maximum-strength assessment (i.e. assessment type, variables), explosive-strength assessment (i.e. assessment type, variables), relationships between strength and punch impact force (i.e. Pearson's r), and strength training interventions (i.e. strength quality type, training phase, duration, frequency, control group, performance measures, results). The authors acknowledge that there are methods of assessing single-joint strength in boxers (e.g., isokinetic dynamometry, hand-grip dynamometry etc); however, this article focuses primarily on multi-joint and compound measures of strength as utilised in performance-based populations (i.e. athletes).

RESULTS

Punch Impact Force

Measurement Devices & Protocols

Since the early 1980s (3), researchers have endeavoured to improve the ecological validity of boxing performance assessments by designing punch-specific dynamometry. However, at present, there is no 'gold' standard for assessing punch performance in boxers. Due to this, a wide variety of assessment devices and protocols have been utilised which has resulted in a large range of punch force values being reported in the literature (544 - 4800 N; see Table 1). Previous work has implemented indirect methods of punch force assessment such as pressure sensors (6,32,49), three dimensional motion capture (11), accelerometers (11); as well as direct measurement methods such as force transducers (3,41,49) and force platforms (13,27). Additionally, in these investigations, maximum punch impact force has been analysed from punches thrown individually (3,27,41,49), in combination (11,13,18), or estimated during a competitive bout (32). Due to these varying factors, and their differing validity and reliability, the direct comparison of punch impact force between measurement devices is not recommended (25). Nonetheless, it is recommened that practitioners who aim to assess punch impact force should select the measurement device based on ecological validity, reliability, and smallest worthwhile change (SWC) (25).

It is important to note that the data presented in Table 1 represents the punch impact forces in a controlled laboratory setting and therefore may be an overestimation of a boxer's punch impact force during a bout. Even though a punch-specific dynamometer may provide a reliable measure of punch impact force, the laboratory environment is much distinct to that of competition where other factors such as ringcraft, judgement of distance, timing and tactical ability are important (25). For example, during a bout, punch impact force may be limited due to (i) an opponent partially evading or parrying a punch, or (ii) the boxer not committing to the punch with maximal 'intent' as there may be the possibility of a counterpunch from the opponent. However, punch-specific dynamometers provide a reliable 'closed' assessment of a boxer's punching potential and enables trainers and support staff (e.g. S&C coaches, sport scientists) to monitor important changes in punch technique, as well as assessing the transferability of strength training from the gym to the ring (13).

Punch Type, Performance Level, Gender & Weight Class

Punch impact force appears to differentiate between boxing performance level (i.e. novice, intermediate and elite) (11,41), gender (27), weight class (32,49), and punch type (41) (see Table 1 for more details). There are three main punches in boxing: straights, hooks and uppercuts. A skilled boxer will vary their punches and lines of attack with singles and combinations to create opportunities to succeed in hitting the opponent. The straight lead, more commonly known as a 'jab,' is one of the most important punches in boxing (21). Whatever the body type or style of the boxer, a competent jab can keep an opponent out of range and off balance, as well as making openings for counters and combinations to follow (21). The straight rear hand, also known as a 'cross,' is traditionally thought to be a more 'damaging' punch than the jab. The larger punch impact force of a cross is most likely due to the punch involving a greater impulse (or 'drive') of the rear leg and subsequent rotational force production of the hips (15,23,41). Nonetheless, the cross forms a close link with the jab, as the jab creates the openings for the cross to land (21). The hook, unlike a straight punch, is delivered with a bent arm applied by a rotational motion around the vertical axis of the body. Due to this unique movement, a hook produces higher impact forces than straight punches (6,11,13). Additionally, a hook can be very effective as the punch can land outside the line of the opponent's vision (21). Consequently, a hook can be the most damaging of all the punches as the impact is transmitted across the opponent's head or body (49). An uppercut is mechanically different to a straight or a hook. The uppercut is thrown in a 'upward' movement, initiated from a drive of the legs in which the knuckle part of the glove faces the opponent and the arm travels at an angle of 90 degrees to the floor. However, due to this specific motion of the uppercut (i.e. upward movement and impact), and as dynamometers are generally constructed for punches that are thrown horizontal to the ground (i.e. straights and hooks), there is a lack of research of this punching technique.

INSERT TABLE 1 HERE

Strength Characteristics of Boxers

Maximal-strength

Maximal-strength is the ability to voluntarily generate maximum force without a time constraint (52). Further, previous research has found a strong relationship between maximal-strength and rate of force development (RFD) (1). The maximal-strength capabilities of the lower- and upper-body have traditionally been assessed via the one repetition maximum (1RM) back squat and bench press. However, the isometric mid-thigh pull (IMTP), isometric squat (ISQT) and isometric bench press (IBP) assessments are increasing in popularity in athletic populations due to their simplicity, safety and time-effective protocols (17). Maximal-strength assessments can support pracititioners (i.e. sport scientists, S&C coaches etc) direct programming by highlighting if a boxer is 'strong' or 'weak' for their performance level or weight class. Tests such as the IMTP give practitioners an insight into the potential role that maximal-strength development may have on improving a boxer's punch impact force. In the lower-body, elite amateur male boxers can produce peak forces of 2048 - 2626 N (32.0-33.8 $N{\cdot}kg^{-1}$) (12,27) (see Table 2). Compared to other combat sports, these values demonstrate that elite amateur boxers have similar lower-body maximal-strength compared to collegiate wrestlers (2645 ± 465 N; 33.9 ± 6.0 N/kg) (30) and elite MMA fighters (2062 – 3870 N; 27.2 – 41.6 N/kg) (53). However, the maximal-strength values of these combat sport athletes are lower than other elite level sports such as rugby league (3833 ± 675 N; 38.0 ± 4.7 N/kg) (48) and athletics (3522 ± 634 N; 39.6 ± 4.6 N/kg) (31). In the upper body, elite amateur male boxers can produce peak forces of 677 - 1018 N (see Table 2) (12,27). Unlike the IMTP and ISQT, there is a lack of studies investigating the IBP peak force values of elite athletes, therefore making it challenging to compare the upper-body maximal-strength qualities of elite boxers to that of other combat sport or team-sport athletes. Further, it is important to note that there is also a dearth of maximal-strength values for elite female boxers. As far as the authors are aware, the only study that has investigated the strength qualities of elite female boxers has been from Loturco et al's (27) group. The researchers reported elite amateur female boxers can produce peak forces of 1808 ± 315 N and 727 ± 95 N in both the lower- and upper-body respectively (see Table 2). Interestingly, even though there were large differences between male and female elite amateur boxers for both upper- and lower-body absolute maximal-strength, it was only lower-body maximal-strength that was statistically different between genders. This suggests that lower-body absolute maximal-strength may be a differentiating factor in explaining the discrepancies in punch impact force between male and female elite boxers (27). However, it is important to note that Loturco et al's (27) group did not report the body mass (or relative peak force) of the participants, and therefore may explain the differences in absolute maximum-strength between genders.

INSERT TABLE 2 HERE

Explosive-strength

Explosive-strength is a colloquial coaching term used to describe an athlete's ability to exert maximal force in minimal time (52). However, as nothing explodes in the human body, some scientists argue that the word 'explosive' should not be utilsed when describing athletic movement (51). Therefore, it is recommended that precise mechanical terms such as rate of force development (RFD), impulse or power should be used instead (46). Nonetheless, 'explosive' is a clear conceptual term for communication to boxers and coaches, whereas describing an athlete's 'impulse' or 'RFD' ability could cause confusion. The countermovement jump (CMJ) is an explosive-strength assessment often utilised by coaches and sport scientists to ascertain an athlete's ability to rapidly apply force with their lower limbs [4]. The CMJ can be used to monitor explosive-strength adaptation, direct gym programming and to gain insight into the neuromuscular readiness of an athlete. The most utilised and easily accessed variable from a CMJ assessment is jump height. Jump height is a result of the impulsiveness of the lower limbs (37). From one of the author's observations, moderate to large correlations (r = 0.60 - 0.70) were found between boxer's CMJ jump height and landmine punch throw velocity (35). Therefore, due to the potential role that leg impulsivity may have on punching impact force, assessing and developing a boxer's CMJ height may be important to trainers and support staff. Previous researchers investigating the CMJ ability of elite male amateur boxers have reported mean values of 36.0 to 43.1 cm (12,18,19,27,34,38) (see Table 3). Further, Haugen et al's group (19) from the Norwegian Olympic Training Centre provides an extensive database of CMJ normative values (~ 1577 athlete CMJ assessments) consisting of elite national-team athletes from different sports collected over several decades. Haugen et al's study highlights that, in the context of CMJ height, elite amateur male boxers have a lower explosive-strength ability (36.0 ± 4.6 cm) than team-sports such as soccer, volleyball and ice hockey (19). Interestingingly, the elite amateur boxers had a similar CMJ ability to endurance sport athletes such as rowing and cross-country skiing. Additionally, when compared to other combat sports, elite amateur male boxers have a lower explosive-strength ability than elite male taekwondo players (39.9 ± 3.9 cm), karatekas (40.4 ± 6.0 cm), judokas (41.7 ± 4.8 cm) and wrestlers (42.0 ± 6.6 cm). Further, this was also the same finding for elite female amateur boxers (25.1 ± 3.0 cm), who had the lowest CMJ height when compared to other elite female power sports, team-sports and combat sports (wrestling, judo, taekwondo & karate) (19). This relatively low explosive-strength ability in elite boxers is surprising considering the rapid force production capabilities of the legs playing an important role in the punch impact force ability (15,40,41). However, the reason for elite boxers having relatively lower standard of explosive-strength, when compared to other elite sports, is unknown. Further, from one of the author's observations, boxers will jump similar heights in a CMJ and squat-jump (SJ) (concentric-only jump), which suggests poor eccentric utilisation in the lower body (elastic utilisation ratio [EUR] = CMJ height ÷ SJ height) (35,50). Since high impact force punches are preceded by a pre-stretch in the lower body and core musculature, the ability to utilise eccentric activity is important for force transfer in boxing. It may be speculated that, compared to other elite combat sports, boxers have a lower explosive-strength ability due to (i) the specific physical demands of the sport and the requirement of higher aerobic training volumes (i.e. steady-state road running, intervals, sparring etc) and therefore a lack of prioritisation of strength training, and (ii) the 'traditional' training culture within boxing and the lack of education regarding the importance of explosive-strength development.

INSERT TABLE 3 HERE

The Relationship between Strength Characteristics and Punch Force Characteristics

Strength qualities of the lower-body have a large association to athletic performance tasks such as sprinting (39), agility (45), jumping (31), throwing (42) and sprint cycling (43). However, there has been a lack of research investigating the relationship between strength and punch impact force in boxing. Previously, researchers have primarily focused on the *resultant* punch impact force characteristics of elite boxers (3,32,40,41,49), with fewer studies investigating the contributing role of force production from the lower- and upper-body (12). The arm delivers a punch to the opponent's head or body, so visually, it is plausible to assume that the force production capabilities of the upper body musculature (i.e. chest, shoulders, arms) may have an important role in punch impact force. However, in other whole-body sporting movements such as the tennis swing (20), throwing a javelin (4) or shot-put (42), research has highlighted the importance of the force contribution of the legs to performance. Recent mixed-methods research (i.e. ground reaction forces (GRF), electromyography (EMG) and high-speed video analysis) (23), found that punches (straights & hooks) from competitive male boxers are full body rotations, initiated by the legs, producing torque through the hip, torso and upper body. Specifically, during the rotation, muscles are activated sequentially from the ground up, working in concert to maximize velocity and stiffness during impact. Therefore, the force production capabilities of the legs may have an important role in punch performance. Early work by Filimonov et al (15) investigated the contribution of the legs, torso and arms to punch performance in boxing. The researchers observed that when compared to lower-standard boxers, categorised 'masters of sport' and 'knock-out artists' applied a larger leg drive, and superior coordination of their body segments, resulting in a more impactful punch. However, it is important to note that the authors did not report their methodology on how they assessed punch performance. Subsequently, Smith et al (41) observed that punch impact force differentiated between elite-, intermediate, and novice-level boxers (see Table 1), attributing the larger punch impact forces in the elite group to a greater leg drive and larger rotational force production capabilities of the torso. Furthermore, Smith (40) also hypothesised that the cross produces a larger impact force than the jab due to a greater rotation of the trunk and a larger force contribution of the legs during the delivery of the punch. Nonetheless, very little research has investigated the association between the strength qualities of the upper- and lower-body and punch impact force in boxers.

The Relationship between Maximal-Strength and Punch Force Characteristics

In elite amateur male boxers, Dunn et al (12) observed that absolute peak force of the lower-body, assessed through the IMTP assessment, explains 46% of the variation in punch impact force (r = 0.68). Additionally, identical associations were found between absolute maximal-strength and other punch impact variables such as impulse (r = 0.68) and force at 5ms (r = 0.68) (12) (see Table 4). Supporting this, Loturco et al (27) found that absolute peak force, measured through an isometric squat, was largely associated with both jab (r = 0.79) and cross (r = 0.73) impact force in elite male and female amateur boxers. Interestingly, Dunn et al (12) found that *relative* peak force of the lower body (i.e. IMTP peak force normalised to body mass) was not significantly related to punch impact force (see Table 4). Consequently, the boxers' larger body mass (and lean tissue) may somewhat partially explain their greater absolute maximal strength, and therefore larger punch impact force. Moreover, the association between body mass and punch impact force in boxers has been previously reported in the literature (27,41,49). Therefore, based of the available literature at present, the assessment and development of *absolute* maximal-strength in the lower-body of boxers may be a potential avenue for trainers and support staff who aim to optimise punch impact force. Nevertheless, as both amateur and professional bouts are weight categorised, increasing lean body mass (i.e. muscle hypertrophy) is not a viable option for most boxers - unless the aim is to move into a higher weight class.

As a result, it may be beneficial for trainers and support staff to design a programme that aims to develop the absolute maximal-strength of the boxer's legs through primarily neural adaptations without a significant increase in muscular cross-sectional area (CSA).

In the upper-body of elite male and female amateur boxers, Loturco et al (27) found that peak force, assessed via the IBP, was not related to both jab and cross punch force variables. Furthermore, researchers from the Australian Institute of Sport (AIS) Combat Centre (12) observed that IBP peak force in elite male amateur boxers was not related to punch impact force, impulse or force at 5ms (see Table 4). However, IBP peak force was strongly correlated with *relative* punch impact force (r = 0.62) (12). Although more evidence is needed in this area, the lack of association between upper-body maximal-strength and punch impact force may be due to the technical requirements of a punch. As mentioned previously, a punch is initiated by the legs applying significant ground reaction forces (15,23). During this early stage of the punch, the legs are overcoming inertia and therefore the velocity at which the leg musculature produces force is relatively slow. In contrast, the force from the legs is followed by a rotation of the hips and torso, extending the arm towards the opponent at high velocities (23). Therefore, the upper-body musculature (i.e. pectorals, deltoids, triceps) that extend the arm during the terminal phase of the punch contract at a high velocity. As maximal-strength assessments occur at either a slow (i.e. 1 RM) or zero velocity (i.e. isometric tests), it is understandable why punch impact force is more related to peak force of the legs (i.e. IMTP) rather than peak force of the upper-body (i.e. IBP).

INSERT TABLE 4 HERE

The Relationship between Explosive-Strength and Punch Force Characteristics

Lower-body explosive-strength is most commonly assessed in athletic populations using the CMJ. In elite male and female amateur male boxers, Loturco et al (27) found strong relationships between CMJ height and both jab (r = 0.72) and cross (r = 0.80) punch impact forces. Furthermore, strong associations were found between punch impact force and other lower-body explosive-strength exercises such as the squat jump (r = 0.77 – 0.78) and the loaded jump squat (r = 0.83 – 0.85). Supporting work from, Dunn et al (12) observed that both CMJ peak force (r = 0.68) and peak power (r = 0.54) were strongly associated with punch impact force (see Table 5). Additionally, CMJ peak force and peak power were also positively correlated to other punch variables such as impulse and force at 5 ms (r = 0.51 - 0.66) (12). For upper-body explosive-strength, Loturco et al (27) observed a strong relationship between explosive bench press variations and both jab (r = 0.75 – 0.76) and cross (r = 0.78 – 0.79) impact force. However, other researchers (26) found that the upper body explosive-strength of professional male boxers, measured through barbell velocity of a bench press (30-80% of 1RM), only correlated with the velocity of the cross (r = 0.64 – 0.82) but not the jab. As mentioned previously, during a punch, the arm extends the fist towards the opponent at high velocities and therefore the upper-body musculature is required to produce force under these specific high velocity conditions. Therefore, the present literature demonstrates that punch impact force is more related to the 'ballistic' qualities of the upper-body (i.e. bench throw) (26,27) rather than peak force or maximal-strength capabilities (i.e. isometric bench press [IBP]) (12,27). Further, there is some evidence to suggest that there may be double 'peak' in muscle activation during an effective punch (24,29). Immediately before the impact of a punch, some researchers suggest that there is a second pulse of muscular activation that causes the arm, chest and torso to 'stiffen,' creating a larger punch impulse (i.e. effective mass) (24,29,36). This effective mass concept proposes that the upper body may have a important role in the terminal stage of a punch (i.e. the 'second pulse') (23). Therefore, this highlights the importance of a boxer's upper-body explosive-strength qualities (i.e. RFD), rather than their upper-body maximal-strength qualities (i.e. peak force), during the delivery of a punch.

INSERT TABLE 5 HERE

Strength Characteristics of Low, Medium and High Punch Impact Force Boxers

Although there are several investigations that have explored the association between strength qualities of the upper and lower body and punch force characteristics, there has been a lack of studies examining the strength characteristics that may differentiate between punch performance in boxing. Recently, Dunn et al (12) examined the strength qualities of elite amateur boxers who were categorised on their ability to punch with 'low' (1543 ± 112 N), 'medium' (1864 ± 87 N) or 'high' (2305 ± 313 N) impact forces. The research group observed that boxers who punched with high impact forces had significantly greater levels of lower-body *absolute* maximal-strength (IMTP peak force) than boxers who punched with medium and low punch impact forces (see Table 6). Further, the 'high' punch impact force boxers had significantly greater lower-body explosive-strength (i.e. higher peak force and peak power in a CMJ) when compared against boxers that punched with lower impact forces. However, it's important to note that *relative* maximal-strength of the lower body (i.e. IMTP peak force normalised to body mass) did not differentiate between punch impact force ability. Nevertheless it is important to highlight that the 'high' punch impact force group's body mass was significantly larger than the 'low' group. This larger body mass may potentially explain the greater levels of lower-body *absolute* maximal-strength (i.e. more muscle mass) and larger punch impact force (i.e. greater momentum due to a larger body mass) (36). Interestingly, in the upper-body, maximal- and explosive-strength did not differentiate between low, medium and high punch impact force boxers. Therefore, based on the present literature, the assessment and development of *both* absolute maximal-strength and explosive-strength in the lower-body of boxers may be a potential avenue for trainers and support staff who aim to optimise punch impact force.

INSERT TABLE 6 HERE

Strength Training Interventions in Elite Boxing

It is important to note that there has been a lack of experimental research investigating the effect of strength training on punch performance in boxers. However, there has been several observational studies published in elite amateur populations over the course of a microcycle (28), mesocycle (5,6) and macrocycle (22) (see Table 7). However the ability to infer from these findings is limited due to the lack of control groups, standardised protocols and valid punch force dynomometry. Therefore, future experimental studies utilising scientifically rigorous methods are needed to clarify the role that strength training has on punch impact force in both elite amateur and professional boxers.

INSERT TABLE 7 HERE

Conclusions

This critical review provides a novel insight into the role of strength on punch impact force in boxers. In boxers, punch impact force differentiates between performance level (i.e. novice, intermediate and elite) (11,41), gender (27), weight class (32,49), and punch type (41). However, at present, there is no 'gold' standard protocol for assessing punch performance in boxers. The maximal-strength qualities of the lower-body, as well as explosive-strength qualities of both the upper- and lower-body, are largely associated with punch impact force in elite amateur boxers. Specifically, elite amateur boxers who punch with 'high' impact forces have significantly greater levels of lower-body maximal-strength and explosive-strength when compared to elite amateurs who punch with 'low' impact forces. However, the maximal-strength capabilities of the upper-body are not associated with punch impact force and does not differentiate between elite boxers who punch with 'high' and 'low' impact forces. Due to the complex nature of the physical preparation process in boxing (i.e. calorie restriction, weight loss, fatigue), there may be a decrement in strength qualities and punch impact forces throughout a boxer's 'fight camp' in the lead-up to a bout (18). Therefore, the available evidence at present suggests that, for boxers who aim to develop their punch impact force, it may be advantageous to emphasise both maximal- and explosive-strength development of the legs, with only an explosive-strength focus in the upper body.

It should be highlighted that much of the interpretation of existing studies came from correlational analyses and the readers should be aware that correlation does not necessarily indicate causation, for example, Dunn et al's (12) work. Future experimental studies are needed to infer causality regarding the role that strength training has on punch impact force in both elite amateur and professional boxers. Another limitation was that much of the research discussed was primarily conducted with male amateur boxers, with only vey limited investigations in both professional and female cohorts. Additionally, it should be pointed out that this review generalised across weight categories and boxing technical 'styles.' We encourage researchers to address these limitations in future research to improve our knowledge and understanding of strength and conditioning within boxing.

PRACTICAL APPLICATIONS

Given the demanding training process in both amateur and professional boxing, it is important that evidenced-based guidance on strength training is utilised during 'fight camps' to optimise performance and limit non-functional overreaching and injury. Therefore, it is imperative that trainers and support staff (e.g. S&C coach, sport scientist etc) take a gradual and systematic approach to implementing strength training within a boxer's training camp. Due to time availability and the prioritisation of other training sessions (i.e. sparring, aerobic conditioning), and undesired hypertrophy, it is important that the 'minimal effective dose' of strength training (16) is administered to attain the required neuromuscular improvements and transferability to punch impact force.

Maximal-Strength Development

To date, in elite boxers, the present literature suggests that punch impact force is *only* associated with maximal-strength of the lower-body, but not the upper-body (12,27). Additionally, elite boxers who punch with high impact forces have significantly greater levels of lower-body maximal-strength when compared to boxers who punch with low impact forces (12). Therefore, it is recommended that boxers develop the maximal-strength capabilities of their legs through the 'max-effort' method (> 80% 1 repetition maximum [RM]) utilising traditional multi-joint exercises such as squat (i.e. goblet squat, landmine squat, back squat etc) and deadlift variations (i.e. trap-bar deadlift) (52). However, if a boxer is unable to perform these bilateral exercises due to mobility restrictions, injury or a lack of technical competency, single-leg exercises such as split-squats or lunges can provide an adequate unilateral alternative. A simple linear loading progression provides a sound programming strategy for maximal-strength development in boxers who have a limited strength training history. During the off-season or early stages of 'camp', there may be an initial period where loading is < 80 % 1 RM. These extensive 'strength-endurance' sets allow the boxer to attain technical competency in the lift, as well as preparing the musculature for more intensive loading in subsequent training phases. Also, as there is considerable evidence to support that a morphological increase in CSA is one of the main mechanisms underpinning maximal- and explosive-strength development (44), these hypertrophic loading schemes (e.g. 8-12 repetitions, 3 – 5 sets) during the early preparatory phases provide the boxer with a foundational development in strength. However, due to weight classifications in boxing, trainers and support staff should be cautious when implementing a hypertrophic stimulus. This is particularly important consideration during the 'off-season' or early stages of camp when the boxer may be in a calorific surplus (2). Nonetheless, maximal-strength is not only dictated by morphological mechanisms (i.e. CSA), but also neural factors such as motor unit recruitment, synchronisation and rate coding (44). Therefore, targeting neural adaptations from maximal-strength training should be the primary objective during the specific preparatory phases (SPP) of camp. During these latter mesocycles of camp (i.e. SPP), loading can be increased > 80 % 1 RM (i.e. 3 – 5 repetitions, 3 - 5 sets) (44). For boxers who have an advanced strength training age, partial lifts such as ½ squats and ¼ squats (or trap-bar deadlifts from blocks) can be progressively introduced to supplement explosive-strength adaptations and the potential transferability to punching impact force (33). During the final weeks of camp when sparring is precedence and the boxer is exposed to an energy deficit for weigh-ins, low volume concentric (i.e. concentric ¼ squats) or isometric lifts (i.e. ISQT, IMTP or isometric trap-bar deadlift) can be incorporated to maintain maximum-strength but reduce the likelihood of soreness or fatigue. The boxer's maximum-strength can be monitored at selected time points throughout the training camp by utilising isometric assessments (i.e. IMTP, IBP), repetition maximum (RM) tests (i.e. 2-5 RM) or sub-maximal load-velocity predictive equations (17).

Explosive-Strength Development

To date, the present literature suggests that explosive-strength, in both the lower- *and* upper-body, is largely associated with punch impact force in elite boxers (26,27). Additionally, elite boxers who punch with high impact forces have significantly greater levels of lower-body explosive-strength when compared to boxers who punch with low impact forces (12). Therefore, it is recommended that boxers develop their explosive-strength utilising the 'dynamic effort' method (52). This method aims to increase the musculature's rate of force development (RFD) and impulsivity through sub-maximal loads and medium-to-high velocity movements in both the lower-body (e.g. jump-squats, squat-jumps, box jumps, medicine ball throws, trap-bar jumps) and upper-body (e.g. bench press throws, ballistic press ups, land mine throw, bench medicine balls throws) (52). However, maximal-strength is a foundational component of explosive-strength ability (9). In fact, research has demonstrated that the neuromuscular adaptations from maximal-strength training can improve *both* explosive-strength and maximal-strength in athletes who may be relatively weak or who have a limited strength training age (i.e. boxers) (8). As some boxers may not have a consistent strength training history, a maximal-strength emphasised training programme (supplemented with low-volume explosive-strength work) may be an option to develop explosive-strength before specificity is accentuated during the later stages of a camp or career. A simple explosive-strength exercise, such as the countermovement jump or medicine ball throw, provides a time-efficient exercise prior to (or between sets of) maximal-strength exercises (i.e. back squat &

bench press). Regular monitoring of CMJ variables (i.e. jump height, RSI_{mod}), using force platforms, contact mats or mobile apps, may help trainers and support staff to gain an insight into the boxer's lower limb explosive-strength adaptations (7). Additionally, the bench press throw, or seated medicine ball throw, can be utilised to monitor the explosive-strength adaptations of the boxer's upper body (12,27,28).

Special-Strength Development

Special-strength training applies the principle of specificity (i.e. dynamic correspondence) by utilising specialised resistance exercises that aims to improve the athlete's competition exercise and performance in their sport (47). As straights, hooks and upper cuts require a rapid whole-body RFD movement in the sagittal, frontal, and transverse planes (23), these punches can be replicated utilising specific exercises. Therefore, explosive whole-body and multi-planer exercises such as medicine ball throws and land mine punches can be implemented at certain stages of camp to increase the transfer to punch impact force (35,36). Similar to an effective punch, these exercises require force to be rapidly generated from the legs, and transferred through the trunk, shoulders and arms. As mentioned previously, there is some evidence to suggest that there may be double 'peak' in muscle activation during the final stage of an effective punch (24,24,29,36). Therefore, specific exercises, such as isometric holds at the terminal part of a punch or an isometric land mine press, may be added in at specific stages of the camp to increase the transferability to punch impact force (35,36). The boxer's special-strength can be monitored throughout the training camp by utilising the landmine punch throw assessment (35). This test assesses the boxer's ability to produce a high impulse in a movement pattern similar to a cross. During the landmine punch throw, barbell velocity is measured over a series of loads (i.e. 20 → 40kg) by a linear position transducer or accelerometer. Alternatively, the medicine ball [backhand] throw (i.e. 3kg medicine ball) for distance can be utilised as a replacement field-based test.

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Table 1

Table 1. Punch impact force (punch type, performance level, gender & weight class), measurement tool and protocol in elite amateur and professional boxing

Author	Year	Performance Level (n)	Gender	Age	Body mass (kg)	Punch Type	Variable		Results	Measurement Tool	Measurement Protocol
Smith et al (41)	2000	Elite (n = 7)	Male	23.1 ± 1.2	69.9 ± 8.6	Straight (rear)	Peak force (N)	4800 ± 227	Significant differences between elite & intermediate (*P* <*0.05*), and intermediate & novice (p < 0.05) for punch impact force. Straight (rear) produced significantly larger impact force than straight (lead) for all groups (p < 0.05)	Wall-mounted force plate (triaxial piezoelectric force transducers) within manikin	4 x 2 minute rounds of maximum-effort straight punches (rear & lead) incorporating single-, 2- & 3-punch combinations in sequence to an audio cue. 330 Hz sampling rate. Maximum individual punch force used for analysis.
						Straight (lead)		2847 ± 225			
		Intermediate (n = 8)		23.5 ± 3.3	73.4 ± 8.2	Straight (rear)		3722 ± 133			
						Straight (lead)		2283 ± 126			
		Novice (n = 8)		23.6 ± 3.2	78.5 ± 8.9	Straight (rear)		2381 ± 116			
						Straight (lead)		1604 ± 97			
Smith (40)	2006	Elite (n = 29)	Male	21.0 ± 2	67.0 ± 10.0	Straight (rear)	Peak force (N)	2643 ± 1273	NR	NR	Maximum individual punch force used for analysis.
						Straight (lead)		1722 ± 700			
						Straight (rear) to body		2646 ± 1083			
						Straight (lead) to body		1682 ± 636			
						Hook (rear)		2588 ± 1040			
						Hook (lead)		2412 ± 813			
						Hook (rear) to body		2555 ± 926			
						Hook (lead) to body		2414 ± 718			
Atha et al (3)	1985	Professional (n = 1)	Male	NR	NR	NR	Peak force (N)	4096	NR	Cylindrical padded 7 kg pendulum with a piezoelectric force transducer	Seven maximum non-specified punches were recorded. The third punch met criteria (punch delivery in line with longitudinal axis of target mass, contact was central & mass was displaced without undue rotational energy) and used for analysis
Walilko et al (49)	2005	Elite (n = 7)	Male	NR	50.8 ± 0.0	Straight (rear)	Peak force (N)	3336 ± 559	Significant difference in peak punch force between weight classes (*P* = 0.02)	Hybrid III dummy equipped with a 6-axis load cell & Tekscan pressure sensor	Instructed to maximally punch the dummy three times with dominant hand
					63.0 ± 0.0	Straight (rear)		2910 ± 835			
					74.8 ± 0.0	Straight (rear)		2625 ± 543			
					100.0 ± 0.0	Straight (rear)		4345 ± 280			
Pierce et al (32)	2006	Professional (n = 12)	Male	25.5 ± 2.1	60.4 ± 1.9	Not specified	Peak force (N)	3056 ± 704	There was not a significant correlation between punch force and weight class (r = .22, p > .05). However	Bestshot force sensor system embedded in glove. Force sensor communicated information	For all fights, bestshot receiver was placed 10 m from ringside & recorded all data. Each boxer utilised the modified boxing
				27.3 ± 7.4	64.3 ± 2.6	Not specified		3680 ± 1123			
				31.5 ± 9.2	75.5 ± 0.3	Not specified		1647 ± 107			

				21.0 ± 1.4	81.3 ± 1.1	Not specified		4495 ± 1221	heavyweight boxer's punch force was significantly larger than junior lightweight boxers (p < .05)	to a remote receiver outside of ring. Glove calibrated for impact forces using a drop platform prior to testing.	gloves within their scheduled bouts. Fights were otherwise conducted in a normal manner.
				31.5 ± 0.7	99.4 ± 0.6	Not specified		3212 ± 484			
Čepulėnas et al (6)	2011	Elite (n = 10)	Male	22.5 ± 3.4	71.9 ± 15.2	Straight (rear)	Peak force (N)	2309 ± 305	NR	Kiktest-100 punch bag-based dynamometer & sensor element	NR
						Straight (lead)		1813 ± 370			
						Hook (rear)		2913 ± 442			
						Hook (lead)		2502 ± 250			
Loturco et al (27)	2016	Elite (n = 9)	Male	25.9 ± 4.7	64.6 ± 12.1	Straight (rear)	Peak force (N)	1368 ± 266	Males produced significantly larger rear-hand and lead-hand straight punch impact forces than females (p < .05; d ≥ 1.28)	Body shield-covered force platform (AMTI) was mounted on the wall at a height of 1 m perpendicular to the floor. Athletes executed punches at a height of between 1.0 and 1.76 m. Competition gloves used for punches.	Specific warm-up consisted of straight punches to the body shield. The boxers performed 6 straight punches from a self-selected position (3 rear straights, 3 lead straights). A 15s and a 1 min rest interval was allowed between conditions. Verbal motivation was provided.
						Straight (lead)		1212 ± 270			
		Elite (n = 6)	Female	25.9 ± 4.7	64.6 ± 12.1	Straight (rear)		988 ± 192			
						Straight (lead)		933 ± 165			
Dunn et al (13)	2019	Elite (n = 15)	Male	17.5 ± 0.5	73.0 ± 14.0	Straight (rear)	Peak force (N)	1818 ± 332	The PI showed 'very good' reliability and accuracy (< 0.1% error). CV%: straight (lead) 4.4-13.6%; straight (rear) 2.0-6.8%; hook (lead) 2.3-8.3%; hook (rear) 2.3-8.2%	Punch measurement apparatus called the 'punch integrator' (PI) which consisted of a wall-mounted S-beam load cell (KAC-E) enclosed with a 270mm punch pad. PI adjusted to shoulder height of each participant. Load cell sampled continuously at 2000 Hz.	The 3-minute punch test (3MPT) involved 6 x 30s cycles of punching. Each cycle was triggered by a light and audible beep every 5s followed by a 5s recovery. Self-selected distance from PI. Three different punch combinations involved (i) straights, (ii) hooks (lead), and (iii) hooks (rear)
						Straight (lead)		841 ± 180			
						Hook (rear)		2622 ± 288			
						Hook (lead)		2481 ± 428			
Halperin et al (18)	2016	Professional (n = 1)	Male	23	80	Straight (rear)	Peak force (N)	3500	NR	NR	NR
Dinu et al (11)	2020	Elite (n = 15)	Not reported	21.1 ± 3.0	73.6 ± 17.9	Straight (rear)	Peak force (N)	3158 ± 1467	Elite produced significantly larger forces than junior boxers for all punches (p < .01)	Participants wore a movement Biomech Link suit (Xsens Technologies). This suit was composed of 17 miniature IMUs strapped onto the body. Each IMU contained a 3D gyroscope, a 3D accelerometer, and a 3D magnetometer in an 18 g	All participants completed a standardised warm-up. The participants were asked to perform 3 punches (cross, hook and uppercut) with, at first, their front hand, then, their rear hand, and finally, a combo: front hand immediately followed by rear hand. A series of 3 punches was executed for each technique.
						Hook (rear)		2999 ± 1818			
						Uppercut (rear)		3242 ± 1767			

		Junior (n = 8)		16.1 ± 0.7	61.0 ± 9.3	Straight (rear)		1021 ± 449		box. Sampling frequency of 240 Hz. Based on the linear velocity and acceleration of each segment computed from the IMU, a customised MatLab program calculated the estimate of the GRF distribution and punch force	The instructions were to punch with maximal possible force.
						Hook (rear)		544 ± 235			
						Uppercut (rear)		700 ± 287			

Values are means ± standard deviations (SD) except where stated otherwise (Abbreviations: n = sample size; kg = kilograms; N = newtons; NR = not reported; *p* = probability value; *d* = Cohen's d)

Table 2

Table 2. Maximum-strength characteristics of the upper- and lower-body for elite amateur and professional boxers.

Table 2. Maximum-strength characteristics of the upper- and lower-body for elite amateur and professional boxers

Upper-body								
Author	**Year**	**Performance Level (n)**	**Gender**	**Body mass (kg)**	**Assessment**	**Variable**	**Absolute**	**Relative**
Lopez-Laval et al (26)	2019	Professional (n = 12)	M	70.6 ± 6.4	Bench Press (Smith Machine)	1 RM (kg)	72.0 ± 8.0	1.0 ± 0.1
Loturco et al (27)	2016	Elite amateur (n = 9)	M	NR	Isometric Bench Press	Peak force (N)	1018 ± 26	NR
		Elite amateur (n = 6)	F	NR	Isometric Bench Press		727 ± 95	NR
Dunn et al (12)	2019	Elite amateur (low force puncher; n = 10)	M	61.8 ± 9.4	Isometric Bench Press		677 ± 65	11.0 ± 1.1
		Elite amateur (medium force puncher; n = 8)	M	71.5 ± 7.7	Isometric Bench Press		879 ± 130	12.3 ± 1.8
		Elite amateur (high force puncher; n = 10)	M	78.4 ± 11.0	Isometric Bench Press		679 ± 131	8.7 ± 1.7
Halperin et al (18)	2016	Professional (n = 1)	M	80	Isometric Bench Press		1163	NR
Lower-body								
Author	**Year**	**Performance Level**	**Gender**	**Body mass (kg)**	**Assessment**	**Variable**	**Absolute**	**Relative**
Loturco et al (27)	2016	Elite amateur (n = 9)	M	NR	Isometric Squat	Peak force (N)	2610 ± 951	NR
		Elite amateur (n = 6)	F	NR	Isometric Squat		1808 ± 315	NR
Dunn et al (12)	2019	Elite amateur (low force puncher; n = 10)	M	61.8 ± 9.4	Isometric Mid-thigh Pull		2048 ± 280	33.2 ± 4.0
		Elite amateur (medium force puncher; n = 8)	M	71.5 ± 7.7	Isometric Mid-thigh Pull		2275 ± 245	32.0 ± 2.9
		Elite amateur (high force puncher; n = 10)	M	78.4 ± 11.0	Isometric Mid-thigh Pull		2626 ± 273	33.8 ± 4.2
Halperin et al (18)	2016	Professional (n = 1)	M	80	Isometric Mid-thigh Pull		NR	NR

Values are means ± standard deviations (SD) except where stated otherwise (Abbreviations: M = male; F = female; n = sample size; kg = kilograms; N = newtons; NR = not reported)

Table 3

Table 3. Explosive-strength (CMJ) characteristics of the lower-body for amateur and professional boxers.

Author	Year	Performance Level (n)	Body mass (kg)	Gender	Assessment	Variable	
Haugen et al (19)	2020	Elite amateur (n = 11)	74.0 ± 9.0	M	Countermovement Jump	Jump height (cm)	36.0 ± 4.6
		Elite amateur (n = 17)	61.0 ± 6.0	F	Countermovement Jump	Jump height (cm)	25.1 ± 3.0
Dunn et al (12)	2019	Elite amateur (low force puncher; n = 10)	61.8 ± 9.4	M	Countermovement Jump	Jump height (cm)	41.0 ± 4.0
		Elite amateur (medium force puncher; n = 8)	71.5 ± 7.7	M	Countermovement Jump	Jump height (cm)	42.0 ± 0.7
		Elite amateur (high force puncher; n = 10)	78.4 ± 11.0	M	Countermovement Jump	Jump height (cm)	42.0 ± 5.0
Loturco et al (27)	2015	Elite amateur (n = 9)	NR	M	Countermovement Jump	Jump height (cm)	37.4 ± 4.8
		Elite amateur (n = 6)	NR	F	Countermovement Jump	Jump height (cm)	27.1 ± 3.3
Halperin et al (18)	2016	Professional (n = 1)	80	M	Countermovement Jump	Jump height (cm)	40.0 ± 0.0
San Juan et al (38)	2019	Elite amateur (n = 8)	65.6 ± 10.8	M	Countermovement Jump	Jump height (cm)	43.1 ± 3.7
Rimkus et al (34)	2019	Elite amateur (n = 8)	78.6 ± 15.7	M	Countermovement Jump	Jump height (cm)	35.0 ± 4.0
Wilson et al (50)	2020	Intermediate amateur (n = 15)	65.2 ± 10.7	M	Countermovement Jump	Jump height (cm)	37.0 ± 8.0*
Wilson et al (50)	2020	Junior (n = 15)	50.9 ± 11.3	M	Countermovement Jump	Jump height (cm)	33.0 ± 5.0*

Values are means ± standard deviations (SD) except where stated otherwise (Abbreviations: M = male; F = female; CMJ = countermovement jump; n = sample size; m = metres; NR = not reported; *arm extension was allowed during CMJ)

Table 4

Table 4. The relationship between maximal-strength characteristics (of the upper- and lower-body) and punch performance variables in elite amateur boxers

Author	Year	Performance Level	Body mass (kg)	Gender	Assessment		Punch Variable	Pearson's *r*
Loturco et al (27)	2016	Elite amateur (n = 15)	64.6 ± 12.1	M + F	Isometric Squat (Smith Machine)	Peak force (N)	Cross Impact Force (N)	0.73*
							Jab Impact Force (N)	0.79*
Dunn et al (12)	2019	Elite amateur (n = 28)	70.5 ± 11.7	M	Isometric Mid-thigh Pull	Peak Force (N)	Punch Peak Force (N)	0.68***
							Relative Peak Force (N/kg)	0.13
							Punch Impulse (N.s)	0.68***
							Force at 5ms (N)	0.68***
							Time at 500N (s)	0.59**
						Relative Peak Force (N/kg)	Punch Peak Force (N)	0.08
							Relative Peak Force (N/kg)	0.47*
							Punch Impulse (N.s)	0.02
							Force at 5ms (N)	0.28
							Time at 500N (s)	0.35*
Dunn et al (12)	2019	Elite amateur (n = 28)	70.5 ± 11.7	M	Isometric Bench Press	Peak Force (N)	Punch Peak Force (N)	0.14
							Punch Peak Force (N/kg)	0.62*
							Punch Impulse (N.s)	0.14
							Force at 5ms (N)	0.07
							Time at 500N (s)	0.22

Values are means ± standard deviations (SD) except where stated otherwise (Abbreviations: M = male; F = female; n = sample size; m = metres; NR = not reported; kg = kilograms; N = newtons; N/kg = Newtons per kg of body mass; N.s = Newton seconds; s = seconds). *Correlations significant at $p \leq 0.05$, ** Correlations significant at $p \leq 0.01$, ***Correlations significant at $p \leq 0.001$

Table 5

Table 5. The relationship between explosive-strength characteristics (of the upper- and lower-body) and punch performance variables in elite amateur and professional boxers.

Author	**Year**	**Performance Level**	**Body mass (kg)**	**Gender**	**Assessment**		**Punch Variable**	**Pearson's *r***
Lopez-Laval et al (26)	2019	Professional (n = 12)	70.6 ± 6.4	M	Bench Press (Smith Machine) at 30-80% 1RM	Velocity (m/s)	Cross Velocity (m/s)	0.64 - 0.82*
							Jab Velocity (m/s)	0.40 – 0.53
Loturco et al (27)	2016	Elite amateur (n = 15)	64.6 ± 12.1	M + F	Bench Press (Smith Machine) at > 30% BM	Mean Power (W)	Cross Impact Force (N)	0.79*
							Jab Impact Force (N)	0.76*
					Bench Throw (Smith Machine) at > 30% BM	Mean Power (W)	Cross Impact Force (N)	0.78*
							Jab Impact Force (N)	0.75*
		Elite amateur (n = 15)	64.6 ± 12.1	M + F	Countermovement Jump	Jump Height (m)	Cross Impact Force (N)	0.80**
							Jab Impact Force (N)	0.72**
					Squat-jump	Jump Height (m)	Cross Impact Force (N)	0.78**
							Jab Impact Force (N)	0.77**
					Loaded jump-squat at > 40% BM	Mean Power (W)	Cross Impact Force (N)	0.85**
							Jab Impact Force (N)	0.83**
Dunn et al (12)	2019	Elite amateur (n = 28)	70.5 ± 11.7	M	Countermovement Jump	Peak Force (N)	Punch Peak Force (N)	0.68***
							Punch Peak Force (N/kg)	0.09
							Punch Impulse (N.s)	0.66***
							Force at 5ms (N)	0.61**
							Time at 500N (s)	0.60**
						Peak Power (W)	Punch Peak Force (N)	0.54**
							Punch Peak Force (N/kg)	0.14
							Punch Impulse (N.s)	0.53**
							Force at 5ms (N)	0.51**
							Time at 500N (s)	0.35

Values are means ± standard deviations (SD) except where stated otherwise (Abbreviations: M = male; F = female; BM = body mass; n = sample size; m = metres; m/s = metres per second; NR = not reported; kg = kilograms; N = newtons; N/kg = Newtons per kg of body mass; N.s = Newton seconds; s = seconds). *Correlations significant at $p \leq 0.05$, ** Correlations significant at $p \leq 0.01$, ***Correlations significant at $p \leq 0.001$

Table 6

Table 6. Maximal- and Explosive-Strength Characteristics of low, medium and high punch impact elite male boxers. Adapted from Dunn et al (12)

Strength quality	**Assessment**		**Low (n = 10)**	**Medium (n = 8)**	**High (n = 10)**
Maximal-strength (lower-body)	Isometric mid-thigh pull	Peak force (N)	2048 ± 280	2275 ± 245	2626 ± 273*#
		Relative peak force (N/kg)	33.2 ± 4.0	32.0 ± 2.9	33.8 ± 4.2
Maximal-strength (upper-body)	Isometric bench press	Peak force (N)	677 ± 65	879 ± 130	679 ± 131
Explosive-Strength (lower-body)	Countermovement jump	Peak power (W)	3142 ± 702	3804 ± 708	4087 ± 830*
		Jump height (m)	0.41 ± 0.04	0.42 ± 0.01	0.42 ± 0.05
		Peak force (N)	1438 ± 273	1772 ± 184*	1957 ± 328*
Explosive-Strength (upper-body)	Bench Press Throw	Power (W)	388 ± 75	464 ± 121	479 ± 31

Values are means ± standard deviations (SD) except where stated otherwise (Abbreviations: m = metres; kg = kilograms; N = newtons; N/kg = Newtons per kg of body mass). *significantly different from low force group ($p \leq 0.05$); #significantly different from medium force group ($p \leq 0.05$)

Table 7

Table 7. Strength Training Interventions and Punch Force Adaptations in Elite Amateur Boxers.

Author	Year	Performance Level	Gender	Intervention Type	Training Phase	Duration (weeks)	Frequency per week	Control Group?	Performance Measures	Results
Čepulėnas et al (6)	2011	Elite amateur (n = 10)	Male	Intervention consisted of a two week 'athletic training' phase and then a two week 'special physical training' phase. Exercises in these phases included: 1. **Max-strength** (2 x 2 reps; 80-90% 1RM): Bench Press, sit-ups etc 2. **Explosive-strength** (3 x 6-10 reps): Depth-jumps (0.6m), press ups etc 3. **Special-strength** (3 x 6-10 reps): Landmine throw (5-6kg), landmine press (3-5kg), dumbell (0.5kg) punches, single straight blows to the boxing bag with 0.5–1 kg weights in hands 4. **Speed** (3 x 10 reps): single straight-, low- & side-punches to the air	NR	4	NR	No	Speed (30m sprint), standing long jump (SLJ), handgrip dynomometer, med ball throw (4kg), punch force (Kiktest-100 punch bag-based dynamometer)	**Strength:** significant ↑ in 30m sprint, SLJ, handgrip dynomometer, med ball throw ($p < 0.05$) **Punch Performance:** significant ↑ in cross force ($p < 0.05$), but no significant changes in jab and hook force
Bruzas et al (5)	2015	Elite amateur (n = 8)	Male	"Participants were instructed to perform exercises at maximum velocity": 1. **"Throwing metal barbell upwards with bent arms" i.e. push press** (3 x 10 reps; 15% BM) 2. **"Barbell disc waving" i.e. landmine rotation** (3 x 10 reps; 15% BM) 3. **Depth jumps** (3 x 10 reps; 0.6m box) 3. **Decline press ups** (3 x 10 reps; legs on 0.15m box) 4. **Abdominal leg raises** (3 x 10 reps; 1kg on each leg) 5. **Weighted punches** (3 x 10 reps; 1kg / 1.5kg) (a) straight-, (b) side-, & (c) low-punches	"off-season"	4	3	No	**Punch performance** (Kiktest-100 punch bag-based dynamometer) 1) peak force of single straight, side & low punches to the bag with the rear hand and the front hand 2) straight, side, and low punches at maximum effort hitting the boxing bag for 3 s & 8 s 3) straight punches to hit a boxing bag in a series of 8 × 8 s	**Punch Performance:** 1) Significant ↑ in peak force of low blow (rear) ($p < 0.05$), but no significant improvements to straight (i.e. jab & crosses) or side punches (i.e. lead & rear hooks) 2) Significant ↑ in the summative forces of 3s & 8s punches ($p < 0.05$) 3) Significant ↑ in the summative forces of 8 x 8s punches ($p < 0.05$)

Loturco et al (28)	2020	Elite amateur (n = 8)	Male	Three consecutive days of explosive-strength training at the athlete's 'optimal power load': **Session 1 (6 x 6 reps)**: Bench press, half-squat & jump-squat **Session 2 (5 x 5 reps):** Bench press, half-squat & jump-squat **Session 3 (4 x 4 reps):** Bench press, half-squat & jump-squat	"competitive period"	1	3	No	**Strength:** mean power and peak power for bench press, half-squat and jump-squat **Punch Performance**: relative punch impact forces for both jabs & crosses (standardised & self-selected positions)	**Strength:** small to moderate ↑ in half-squat (*d* = 0.39 - 0.73) and jump-squat (*d* = 0.23 - 0.73) mean power and peak power outputs, however only trivial changes in bench press (*d* = 0.02 - 0.09) **Punch Performance:** small ↑ in both self-selected and standardised position jabs (*d* = 0.36 - 0.38) and crosses (*d* = 0.26 - 0.39)
Kim et al (22)	2018	Elite amateur (n = 15)	Male	**Power circuit** (3 x 8-10 reps; 50-70% 1RM; 10-15s of skipping or punching a bag between exercises): leg extension, incline sit-up, jerk, squat, back extension, lat pull down, deadlift, all body twist, dumbbell press, dumbbell punch **Resistance band & medicine ball circuit** (3 x 8-10 reps; green, blue & black resistance bands; 3, 4 & 5kg med balls): med ball throw, med ball abdominal twist, med ball lunge, med ball abdominal rotations, band shoulder press, band resisted (hips) straight punches, resisted jumps, band resisted (hips) hook punches **Boxing power / shuttle-run:** 3 x 3 minute rounds (1 minute recovery between rounds). Step 1 (8 second intervals) to step 4 (5 second intervals)	"pre-season"	16	3	No	**Strength:** machine-based bench press, squat, isokinetic dynamometer of trunk (30°/sec) & arm (180°/sec) **Punch Performance:** straights and hooks by dominant hand. The dummy face was placed at the same height of the each participant. The participants executed straights and hook three times. Impact of the participants' hand on the target was measured by three axial (x, y, and z) acceleration sensor (Model 4630, Measurement Specialties, USA)	**Strength:** significant ↑ in bench press and squat between pre- and post-training ($p < 0.05$), and in squat between mid- and post-training ($p < 0.05$) **Punch Performance:** significant ↑ in punch power for facial straight ($p < 0.05$) attacks showed gradual improvement at the mid- and post-training compared to pre-training. Significant ↑ in punch power for facial hook ($p < 0.05$) attacks also showed gradual improvement at the post-training compared to pre-training

Abbreviations: 1RM = 1 repetition maximum; reps = repetitions; SLJ = standing long jump; ↑ = improved / improvements; p = probability value; d = Cohen's d; BM = body mass; n = sample size; m = metres; °/sec = degrees per second; NR = not reported; kg = kilograms; s = seconds