AKADEMIA WYCHOWANIA FIZYCZNEGO
im. Bronisława Czecha w Krakowie

Szkoła Doktorska

Autoreferat rozprawy doktorskiej
Monotematyczny cykl publikacji naukowych

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Wybrane aspekty analizy walk kickboxerskich z uwzględnieniem sprawności fizycznej i parametrów fizjologicznych

Promotor:
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Kraków 2023

Serdeczne podziękowanie dla mojego promotora
oraz przyjaciela ***prof. Tadeusza Ambrożego****,*
a także wszystkich, którzy przyczynili
się do powstania niniejszej dysertacji.
„Don't train hard, train smart”
Pracę dedykuje moim rodzicom oraz *żonie Ewie*

Spis treści

1. Monotematyczny cykl publikacji naukowych

Wskazując cykl powiązanych tematycznie artykułów naukowych, pragnę zaznaczyć, iż zostały one wybrane spośród 44 recenzowanych publikacji naukowych, z czego 34 figurują na tzw. liście filadelfijskiej. We wszystkich tych pracach pełnię rolę wiodącego współautora i autora korespondencyjnego. Przedstawione osiągnięcia badawcze wypracowałem podczas kształcenia w Szkole Doktorskiej Akademii Wychowania Fizycznego im. Bronisława Czecha w Krakowie. Na potrzeby niniejszej dysertacji doktorskiej wybrano następujące publikacje naukowe, tworzące zwarty tematycznie cykl:

1. Rydzik, Ł.; Ambroży, T. Physical Fitness and the Level of Technical and Tactical Training of Kickboxers. *Int. J. Environ. Res. Public Health* **2021**, *18*, 1–9, doi:10.3390/ijerph18063088.

   Impact Factor: 4.614 , Punktacja MEiN: 140
2. Rydzik, Ł.; Maciejczyk, M.; Czarny, W.; Kędra, A.; Ambroży, T. Physiological Responses and Bout Analysis in Elite Kickboxers during International K1 Competitions. *Front. Physiol.* **2021**, *12*, 737–741, doi:10.3389/fphys.2021.691028.

   Impact Factor: 4.755 , Punktacja MEiN: 100
3. Rydzik, Ł.; Ambroży, T.; Obmiński, Z.; Błach, W.; Ouergui, I. Evaluation of the Body Composition and Selected Physiological Variables of the Skin Surface Depending on Technical and Tactical Skills of Kickboxing Athletes in K1 Style. *Int. J. Environ. Res. Public Health* **2021**, *18*, 11625, doi:10.3390/ijerph182111625.

   Impact Factor: 4.614 , Punktacja MEiN: 140
4. Rydzik, Ł.; Mardyła, M.; Obmiński, Z.; Więcek, M.; Maciejczyk, M.; Czarny, W.; Jaszczur-Nowicki, J.; Ambroży, T. Acid–Base Balance, Blood Gases Saturation, and Technical Tactical Skills in Kickboxing Bouts according to K1 Rules. *Biology (Basel).* **2022**, *11*, 65, doi:10.3390/biology11010065.

   Impact Factor: 5.168 , Punktacja MEiN: 100
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Impact Factor: 0 , Punktacja MEiN: 70

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   Impact Factor: 0 , Punktacja MEiN: 70

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   Impact Factor: 1.338 , Punktacja MEiN: 140

Łączna punktacja cyklu publikacji: Impact Factor: 20,489; punktacja MEiN: 830

Pozostałe publikacje autora rozprawy doktorskiej:

1. **Rydzik, Ł**. The Comparison of the Level of Aggressiveness of Oyama Karate and Mixed Martial Art Fighters. *Appl. Sci.* **2022**, *12*, doi:10.3390/app12178446.
2. **Rydzik, Ł**. Fitness Profile of Oyama Karate and Kickboxing Athletes – Initial Concept. *Arch. Budo Sci. Martial Arts Extrem. Sport.* **2021**, *17*, 19–24.
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Ogólny dorobek naukowy: Impact Factor: 137,967; punktacja MEiN: 4790;
H-Index: 7

2. Streszczenie

Kickboxing jest sportem walki, w którym wyróżnia się wiele form rywalizacji. Najmniej ograniczoną formułą startową w odniesieniu do arsenału stosowanych technik oraz siły ich wykonywania jest formuła K1 Rules. Dozwolone są w niej wszystkie techniki ręczne oraz nożne wykonywane bez ograniczeń siły uderzenia. Ze względu na związaną z tym widowiskowość systematycznie wzrasta popularność tego sportu. Coraz większe zainteresowanie wykazuje nim także środowisko badawcze, w którym dokonywane są coraz bardziej wszechstronne analizy pojedynków. W niniejszej dysertacji skoncentrowano się na wybranych aspektach analizy walk kickboxerskich z uwzględnieniem sprawności fizycznej i parametrów fizjologicznych. Badania te zostały przeprowadzone na grupach zaawansowanych zawodników kickboxingu, którzy rywalizują w formule K1.

Kompleksowo pojęta analiza walki została przeprowadzona pod kątem sprawności fizycznej, wskaźników wyszkolenia techniczno-taktycznego (aktywność, skuteczność i efektywność ataku), składu tkankowego ciała oraz parametrów fizjologicznych podczas walki. Badania dotyczące określenia poziomu sprawności fizycznej zostały przeprowadzone za pomocą wybranych prób z Międzynarodowego Testu Sprawności Fizycznej oraz Europejskiego Testu Sprawności Fizycznej. Weryfikację składu ciała przeprowadzono metodą impedancji bioelektrycznej. Pomiarów fizjologicznych dokonano za pomocą specjalistycznego termometru, miernika pH, gazometru, pulsometru oraz analizatora mleczanu. Wyniki badań oraz szczegółowe ich interpretacje opublikowano w ośmiu powiązanych tematycznie artykułach naukowych, stanowiących kompletną analizę walki przeprowadzoną na potrzeby niniejszej dysertacji doktorskiej.

Wyniki tych badań przedstawiają, wartości wskaźników wyszkolenia techniczno-taktycznego, oraz pokazują powiązane parametry sprawności fizycznej i składu ciała, które w sposób istotny statystycznie wpływają na wartość wskaźników. W toku analizy walki odnotowano silnie wzrastający stres fizjologiczny oraz zaburzenia równowagi kwasowo-zasadowej. Wykazano istotne statystycznie zmiany stężenia mleczanu we krwi oraz tętna, które wzrastały z każdą rundą pojedynku.

Opublikowane wnioski wskazują na powiązanie sprawności fizycznej oraz składu ciała ze wskaźnikami wyszkolenia techniczno-taktycznego. Przedstawiają również istotne statystycznie zmiany w reakcjach fizjologicznych. Dają możliwość wyciągania praktycznych wniosków wpływających na jakość szkolenia w kickboxingu oraz zwiększają zakres opcji dokonywania kontroli trenerskiej.

3. Abstract

Kickboxing is a combat sport with many forms of competition. The least restricted fighting formula in terms of the range of techniques used and the power used to perform them is the K1 Rules. According to these rules, all kickboxing punches and kicks are allowed with full power. Due to the associated spectacle, the popularity of the sport is steadily growing. The research community is also showing increasing interest, with more and more comprehensive analyses of K1 kickboxing bouts. This dissertation focuses on selected aspects of the analysis of kickboxing bouts with regard to physical fitness and physiological parameters. This research was carried out on groups of highly trained kickboxing athletes who compete under the K1 rules.

A comprehensive analysis of the bouts was conducted in terms of physical fitness, indices of technical and tactical training (activeness, efficiency, and effectiveness of attack), body tissue composition, and physiological parameters during the bout. The examinations aimed to evaluate the level of physical fitness were performed using selected tests from the International Physical Fitness Test and the European Physical Fitness Test. Verification of body composition was conducted using the bioelectrical impedance method. Physiological measurements were made using a specialized thermometer, pH meter, gasometer, heart rate monitor, and lactate analyzer. The results of the examinations and their detailed interpretations were published in eight thematically related scientific papers that constitute a complete analysis of the kickboxing bout conducted for this doctoral dissertation.

The results of this research include the values of indices of technical and tactical skills and show the related parameters of physical fitness and body composition which statistically significantly affect the value of the indices. Strongly increasing physiological stress and acid-base imbalance were found during the analysis of the bouts. Statistically significant changes in blood lactate levels and heart rate were demonstrated to increase with each round of the bout.

The published findings indicate a relationship of physical fitness and body composition with indices of technical and tactical skills. They also show statistically significant changes in physiological responses. They provide an opportunity to draw practical conclusions that affect the quality of kickboxing training and increase the range of options for coaching control.

4. Wprowadzenie

Kickboxing jest sportem walki, w którym rywalizacja polega na walce przy zastosowaniu kopnięć oraz uderzeń rękami [1]. Uczestnicy rywalizacji w formie amatorskiej noszą komplet ochraniaczy, co znacznie obniża stopień urazowości [2]. W trakcie starcia warunki walki sportowej ulegają dynamicznym zmianom, dlatego zawodnicy muszą charakteryzować się bardzo dobrym przygotowaniem motorycznym. W kickboxingu wyróżnia się wiele odmian rywalizacji (*point fighting*, *light contact*, *kicklight*, *full contact*, *low kick*), które różnią się szczegółowymi zasadami. Na świecie funkcjonuje kilka międzynarodowych organizacji zrzeszających miłośników tego sportu. Największą i najbardziej prestiżową jest Word Association of Kickboxing Organizations (WAKO) [3].

Proces treningowy w tej dyscyplinie charakteryzuje się wszechstronnością zarówno pod względem intensywności treningu, jak i kształtowania zdolności motorycznych [4,5]. Starcie w walce sportowej w kickboxingu charakteryzuje się acykliczną pracą i częstą zmianą warunków walki (wymagania koordynacyjno-zwinnościowe). Wpływa to holistycznie na trenujących i wszechstronnie angażuje cały organizm, aktywując wszystkie grupy mięśni. Ciągle zmieniająca się sytuacja w trakcie walki wymaga od zawodnika szybkiej i precyzyjnej orientacji oraz błyskawicznego reagowania na akcje przeciwnika. Walka trwa zazwyczaj trzy razy po dwie minuty i cechuje się zmienną intensywnością wysiłku [6]. Wysiłek fizyczny podczas walki sportowej i poprzedzający ją trening specjalistyczny w kickboxingu bazuje na obciążeniach submaksymalnych i maksymalnych. Podstawowe źródło energetyczne stanowi zatem glikoliza beztlenowa, natomiast pod koniec starcia zawodnik wykorzystuje źródła tlenowe (niezbędna optymalna wytrzymałość tlenowa i beztlenowa) [7].

Kwerenda literatury wykazuje różnorodne problemy badawcze, które weryfikowali naukowcy z całego świata. W dotychczasowych badaniach oceniano budowę ciała, odpowiedź fizjologiczną oraz analizę ruchu (biomechanikę) u zawodników podczas symulacji walki lub treningu [8–11]. Badania przeprowadzone przez Moreira ze współpracownikami dotyczyły wpływu walki w kickboxingu w odniesieniu do zmian poziom kortyzolu oraz immunoglobulin [12]. Badania zawodników kickboxingu wielokrotnie podejmował Ouergui wraz ze współpracownikami. Przedstawił między innymi analizę czasowo-ruchową zawodowego kickboxingu [9] oraz skupił się na analizie techniczno-taktycznej zawodów kickboxingu na wysokim poziomie [8]. Analizy dotyczyły także oceny urazowości [13]. Volodchenko ze współpracownikami opublikował wyniki przydatności wykorzystywania testów śliny w kickboxingu [14]. Podrigalo z zespołem zajął się prognozowaniem wygranej w kickboxingu na podstawie analizy wskaźników morfologicznych, fizjologicznych, biomechanicznych i psychofizjologicznych [15]. Sliva z zespołem naukowców przeprowadził badanie, w którym przeanalizował psychologiczne oraz fizjologiczne aspekty walki sportowej w zawodowym kickboxingu [16]. Ambroży i współpracownicy opracowali nowoczesną formę weryfikacji sprawności specjalnej dla zawodników kickboxingu [17] oraz przeanalizowali wpływ ograniczeń związanych z pandemią Covid-19 na sprawność fizyczną zawodników [18]. W ostatnich badaniach zweryfikowali wpływ cross-treningu na sprawność fizyczną specjalną oraz ogólną wśród zawodników kickboxingu [19].

Skuteczność technik kickboxingu zasadza się na wyczuciu możliwości oddania uderzeń (jednego lub całej serii), w których energia dostarczana jest z procesów beztlenowych, natomiast wszystkie przerwy między seriami ciosów cechują się metabolizmem tlenowym [20]. Decydujące momenty walki, po których często zapada rozstrzygnięcie, opierają się na ścieżce beztlenowej niekwasomlekowej (alaktycznej), jednakże konieczny jest również wysoki poziom wydolności tlenowej w celu szybkiej restytucji między dynamicznymi wysiłkami beztlenowymi. Potwierdzają to dane prezentowane przez Zabukovec i Tiidus, którzy wykazali, że elitarni kickboxerzy cechują się wysokim poziomem wydolności aerobowej i anaerobowej wraz z wysokim zapleczem siłowym [21]. Również Ouergui i współautorzy twierdzą, że trening kickboxingu powinien być ukierunkowany na poprawę beztlenowej wydolności zawodników [10]. Wysiłki wykonywane podczas zawodów przez zawodników uprawiających sporty walki (kickboxing, boks, taekwondo i zapasy) wymagają bardzo dobrej wydolności anaerobowej, tę zaś – jak wykazały badania – można także poprawić przez podanie wodorowęglanu sodu [22–24].

Ponadto sporty walki charakteryzuje otwarta struktura zadania, co pociąga za sobą konieczność utrzymywania funkcji poznawczych na odpowiednim poziomie w czasie całego starcia [25]. U sportowców najczęściej bada się następujące zdolności kognitywne: percepcję wzrokową, szybkość przetwarzania informacji, planowanie i adekwatność decyzji. W badaniach laboratoryjnych do oceny poziomu niektórych z wymienionych parametrów wykorzystuje się pomiary szybkości i trafności reakcji na bodźce wzrokowe [26]. Wiele z nich ujawnia związek między wynikami wspomnianych testów, a fizjologicznymi zmianami wywołanymi przez różne wysiłki stosowane w badaniach laboratoryjnych. Bezpośrednio po wykonaniu intensywnego wysiłku wywołującego kwasicę metaboliczną wyniki testu czasu reakcji i testu Stroopa są gorsze niż w spoczynku, ale po 15-minutowym wypoczynku ulegają częściowej normalizacji [27]. Testy wysiłkowe w połączeniu z równoległymi próbami psychometrycznymi nie odwzorowują jednak w pełni struktury zadania typowego dla realnej walki. Dlatego kluczowe znaczenie ma prowadzenie badań w warunkach startowych, co pozwala na obiektywną i realną ocenę zachodzących zjawisk. W większości przypadków skala trudności w realizacji mentalno-fizycznego wyzwania na oficjalnych zawodach sportów walki jest znacznie większa w porównaniu do laboratoryjnych prób psychofizycznych [28,29]. Dlatego w niniejszej dysertacji przedstawiono wynik badań analizowane podczas realnych startów zawodników.

W strukturze pojedynku walka kickboxingu w formule K1 jest zbliżona do muay thai oraz częściowo do pojedynku w pełno kontaktowych odmianach karate lub boksu. Również w tych dyscyplinach systematycznie przeprowadzane są liczne analizy oraz eksperymenty naukowe [30–34]. Badacze często porównują zawodników kilku dyscyplin, aby określić różnice w predyspozycjach lub osobowości [35]. Podobna tendencja dotyczy opracowania testów sprawności fizycznej specjalnej, które powstały dla kickboxingu [17], karate [36], muay thai oraz mieszanych sztuk walki [37].

W przypadku funkcji wykonawczych w czasie walki z nieznanym przeciwnikiem występuje bardzo duża różnorodność bodźców i wiele możliwości wyboru reakcji na nie, co minimalizuje efekt uczenia się obecny w czasie powtarzanych badań laboratoryjnych. Z powodu tej różnorodności o wyniku rywalizacji, obok wydolności fizycznej, decyduje poziom umiejętności techniczno-taktycznych [38]. Dzięki określeniu wskaźników wyszkolenia techniczno-taktycznego możliwe jest diagnozowanie umiejętności startowych zawodnika. Analiza polega na obliczeniu, przy zastosowaniu odpowiednich wzorów, poziomu aktywności ataku, efektywności ataku i skuteczności ataku. Tego rodzaju analizy działań technicznych w sportach walki zostały zapoczątkowane w judo, w którym systematycznie dokonuje się podobnych pomiarów [39–43]. Na podstawie schematów określonych dla judo dostosowano formuły do wymagań analizy walki kickboxingu w formule K1.

Literatura przedmiotu niedostatecznie precyzowała zależności między wskaźnikami wyszkolenia techniczno-taktycznego zawodników kickboxingu w formule K1. Jak wskazano powyżej, badacze skupiali się na analizie walk symulowanych oraz weryfikowali głównie walkę kickboxingu w formule *full-contact*.

Dlatego na potrzeby niniejszej dysertacji opracowano serię artykułów naukowych, szczegółowo weryfikujących wymienione zależności. Analizie poddano korelację między przewinieniami zawodników a wskaźnikami przygotowania techniczno-taktycznego [44]. Wskazano, które zdolności motoryczne bezpośrednio przekładają się na poziom wyszkolenia zawodników [38]. Poszukiwano związków między parametrami fizjologicznymi a prezentowanymi umiejętnościami techniczno-taktycznymi [45–47]. W celu wyskalowania wskaźników dokonano wstępnego określenia poziomu prezentowanych wskaźników przygotowania techniczno-taktycznego dla zawodników różnej rangi, które pozwoliły na interpretację wskaźników odnotowanych w poprzednich badaniach [48]. Badania te stały się inspiracją dla innych naukowców, którzy wykorzystali opracowane wskaźniki na potrzeby własnych dociekań [49].

Szczegółowa weryfikacja przeprowadzona na potrzeby niniejszej dysertacji doktorskiej pozwoliła uzupełnić lukę w wiedzy na temat walki kickboxingu w formule K1 i przyczyniła się do ulepszenia procesu treningowego oraz podniesienia jakości kontroli trenerskiej. Zestawione artykuły naukowe zyskały dużą popularność wśród naukowców, o czym świadczy systematycznie rosnąca liczba cytowań.

5. Cel pracy

Głównym celem niniejszej dysertacji były wybrane aspekty analizy techniczno-taktycznej walk kickboxerskich z uwzględnieniem poziomu sprawności fizycznej oraz odpowiedzi fizjologicznej podczas walki.

5.1. Pytania badawcze

W toku publikacji serii artykułów naukowych wyszczególniono następujące problemy szczegółowe, na które udzielono odpowiedzi dzięki realizacji Indywidualnego Planu Badawczego:

1. Jak prezentuje się aktywność, efektywność i skuteczność ataku badanych kickboxerów podczas walki w formule K1, na podstawie obliczonych wskaźników wyszkolenia techniczno-taktycznego?
2. Czy występują różnice w wartościach wskaźników wyszkolenia techniczno-taktycznego w odniesieniu do poziomu rywalizacji w formule K1?
3. Jaka jest ilościowa i jakościowa gradacja przewinień podczas walki kickboxingu w formule K1?
4. Czy występuje zależność między liczbą przewinień a wskaźnikami wyszkolenia techniczno-taktycznego?
5. Zastosowanie jakiej techniki przynosi największe korzyści punktowe w zakresie efektywności i skuteczności ataku?
6. Czy występuje związek między poziomem wskaźników sprawności fizycznej a aktywnością, efektywnością i skutecznością ataku zawodników walczących w formule K1?
7. Czy występuje związek między składem ciała a aktywnością, efektywnością i skutecznością ataku zawodników walczących w formule K1?
8. Jak kształtują się zmiany w temperaturze i pH skóry podczas walki kickboxingu w formule K1?
9. Jaka jest struktura fizjologiczna zmian wartości tętna oraz stężenia mleczanu we krwi w odniesieniu do walki kickboxingu w formule K1?
10. Jaka jest skuteczność restytucji zawodników kickboxingu w formule K1?
11. Jak przedstawia się wartość wewnętrznego obciążenia startowego w stosunku do pośredniego tętna maksymalnego zawodników kickboxingu w formule K1?

12. Czy podczas walki kickboxingu w formule K1 występują istotne statystycznie zmiany w równowadze kwasowo-zasadowej?
13. Czy występuje związek między równowagą kwasowo-zasadową a wskaźnikami wyszkolenia techniczno-taktycznego?

6. Harmonogram realizacji

Monotematyczny cykl publikacji naukowych			
Autor	**Rok**	**Tytuł**	**Odpowiedź na pytanie badawcze**
Ambroży, Rydzik, Kędra, Ambroży, Niewczas, Sobiło, Czarny	2020	The Effectiveness of Kickboxing Techniques and its Relation to Fights Won by Knockout	5
Rydzik, Niewczas, Kędra, Grymanowski, Czarny, Ambroży	2020	Relation of Indicators of Technical and Tactical Training to Demerits of Kickboxers Fighting in K1 Formula	1, 3,4
Rydzik, Ambroży	2021	Physical Fitness and the Level of Technical and Tactical Training of Kickboxers	1,6
Rydzik, Maciejczyk, Czarny, Kędra, Ambroży	2021	Physiological Responses and Bout Analysis in Elite Kickboxers During International K1 Competitions	1, 9,10
Rydzik, Ambroży, Obmiński, Błach, Ouergui	2021	Evaluation of the Body Composition and Selected Physiological Variables of the Skin Surface Depending on Technical and Tactical Skills of Kickboxing Athletes in K1 Style	1,7,8
Rydzik, Mardyła, Obmiński, Więcek, Maciejczyk, Czarny, Jaszczur-Nowicki, Ambroży	2022	Acid–Base Balance, Blood Gases Saturation, and Technical Tactical Skills in Kickboxing Bouts According to K1 Rules	1, 10, 12,13
Rydzik	2022	Indices of Technical and Tactical Training During Kickboxing at Different Levels of Competition in the K1 Formula	1, 2
Rydzik	2022	Determination Of The Real Training Load Based On Monitoring Of K1 Kickboxing Bouts	11

7. Opis publikacji

Analizę walki kickboxingu w formule K1 rozpoczęto od poszukiwania najbardziej skutecznej techniki, czyli takiej, której zastosowanie najczęściej doprowadza do zakończenia walki przed czasem. W artykule pt. *The Effectiveness of Kickboxing Techniques and its Relation to Fights Won by Knockout* (załącznik 1) dokonano oceny przeprowadzonych obserwacji 156 pojedynków z podziałem na 61 walk amatorskich i 95 profesjonalnych. Analiza statystyczna wykazała, że najczęściej zawodnicy kończą pojedynek przed czasem po zastosowaniu ciosu sierpowego wysokiego. Natomiast z kategorii technik nożnych najbardziej skuteczne okazało się kopnięcie okrężne wysokie. Praktycznym zastosowaniem badania stało się włączenie najbardziej skutecznych technik do struktury kombinacji ćwiczonych podczas treningów technicznych.

Kontynuując szczegółową analizę walki, w kolejnych etapach badań opracowano wzory określające wskaźniki wyszkolenia techniczno-taktycznego służące do obliczenia aktywności ataku, skuteczności ataku i efektywności ataku:

- **Skuteczność ataku (S_a)**

$$S_a = \frac{n}{N}$$

gdzie: n – liczba ataków ocenionych w punktach,
N – suma obserwowanych walk.

* W formule K1 każde czyste trafienie przeciwnika daje 1 punkt.

- **Efektywność ataku (E_a)**

$$E_a = \frac{\text{liczba ataków skutecznych}}{\text{liczba wszystkich ataków}} \times 100$$

*Atakiem skutecznym określa się działanie techniczne, za które przyznano punkt.
* Liczba wszystkich ataków obejmuje wszystkie próby technik ofensywnych.

- **Aktywność w ataku (A_a)**

$$A_a = \frac{\text{liczba zarejestrowanych ataków zawodnika}}{\text{liczba walk stoczonych przez zawodnika}}$$

Po raz pierwszy wykorzystano wymienione wyżej formuły w publikacji pt. *Relation of Indicators of Technical and Tactical Training to Demerits of Kickboxers Fighting in K1 Formula* (załącznik 2). Celem pracy było określenie wskaźników wyszkolenia techniczno-taktycznego oraz rodzaju i liczby przewinień, jakich dopuszczają się zawodnicy kickboxingu walczący w formule K1. Ocenie poddano 31 zawodników rywalizujących podczas Mistrzostw Polski w formule K1, których walki zostały nagrane i szczegółowo przeanalizowane. Wartość skuteczności ataku wyniosła 46,63 ± 11,15, aktywności ataku 91,61 ± 22,86, natomiast efektywności ataku 60,16 ± 6,81. Wyniki badań pokazały, że zawodnicy najczęściej zaliczają dwa przewinienia (38,7%); najwięcej badanych dokonywało zabronionego przytrzymania przeciwnika. Analiza zależności określona przy zastosowaniu korelacji liniowej Pearsona nie wykazała istotnych statystycznie zależności między liczbą przewinień a wskaźnikami wyszkolenia techniczno-taktycznego. Wnioski wyciągnięte z przedstawionej analizy wskazują na potrzebę przestrzegania zawodników przed zbyt długim i częstym przytrzymywaniem zawodnika, dzięki czemu zmniejsza się ryzyko utraty punktu oraz obniżenia ogólnej dynamiki walki.

Jednym z kluczowych elementów wyszkolenia jest odpowiednio rozwinięta sprawność fizyczna. Dlatego na potrzeby kontroli trenerskiej określono poziom poszczególnych zdolności motorycznych w powiązaniu ze wskaźnikami wyszkolenia techniczno-taktycznego, które opublikowano w artykule *Physical Fitness and the Level of Technical and Tactical Training of Kickboxers* (załącznik 3). Badanie przeprowadzono na grupie 20 zawodników kickboxingu, którzy prezentowali wysoki poziom sportowy. Dobór badanej grupy był celowy, a jego kryteria obejmowały staż treningowy oraz poziom sportowy oceniany na podstawie obserwacji przez autorów artykułu i opinii trenera prowadzącego. Badani byli w wieku od 18 do 32 lat, masa ich ciała mieściła się w przedziale 75–92 kg, wysokość ciała 175–187 cm. Sprawność fizyczna została oceniona za pomocą wybranych prób z Międzynarodowego Testu Sprawności Fizycznej oraz Europejskiego Testu Sprawności Fizycznej: tapping, skok w dal z miejsca, pomiar siły uścisku dłoni, siady z leżenia tyłem, skłon tułowia w siadzie prostym, test Coopera. Dodatkowo określono maksymalny pobór tlenu, który zweryfikowano metodą pośrednią przy zastosowaniu testu Margarii. Ponadto dla badanych zawodników obliczono wskaźniki wyszkolenia techniczno-taktycznego, które zweryfikowano przy pomocy rejestru cyfrowego pojedynków.

Zależności między wskaźnikami wyszkolenia techniczno-taktycznego a poszczególnymi próbami sprawności fizycznej obliczono przy pomocy współczynnika korelacji liniowej Pearsona. Wybór testu uwarunkowany był spełnieniem podstawowych założeń, dotyczących zgodności rozkładów badanych zmiennych z rozkładem normalnym oraz jednorodności wariancji. Zgodność rozkładów z rozkładem normalnym oceniono testem Shapiro-Wilka, a do oceny jednorodności wariancji posłużono się testem Levene'a. Wykazano wysoką ujemną korelację wydolności tlenowej z szybkością ruchów kończyny górnej i biegiem zwinnościowym oraz wysoką dodatnią korelację ze skokiem w dal z miejsca i wytrzymałością biegową ($p<0,001$). Wystąpiła też silna zależność między wydolnością a siłą statyczną dłoni i siłą mięśni brzucha ($p<0,001$). Wykazano, że masa ciała koreluje silnie dodatnio z szybkością kończyn górnych i biegiem zwinnościowym, natomiast ujemnie ze skokiem w dal z miejsca i wytrzymałością ($p<0,001$). Osoby szybsze i mające lepszą koordynację były bardziej aktywne, efektywne i skuteczne w ataku. Wyższe wyniki wskaźników uzyskiwali zawodnicy osiągający lepsze rezultaty w próbie skoku w dal z miejsca i w teście Coopera. Skuteczność ataku korelowała z siłą mięśni brzucha. Badani sportowcy chrakteryzujący się wyższym poziomem VO_2 max byli bardziej aktywni, efektywni i skuteczni w ataku.

Analiza przedstawionych badań prowadzi do wniosku, że aktywność, skuteczność i efektywność zawodników wyrażona za pomocą wskaźników techniczno-taktycznych wykazuje silną zależność od poziomu maksymalnego poboru tlenu (VO_2max). Wynika z tego, że kickboxerzy powinni wypracować w okresie przygotowawczym, a następnie podtrzymywać w okresie startowym optymalny poziom wydolności tlenowej, to zaś powinno mieć bezpośredni wpływ na ich możliwości startowe. Dodatkowo poziomy szybkości oraz zwinności mają znaczenie dla działalności startowej zawodników, mierzonej wskaźnikami przygotowania techniczno-taktycznego. Zależność ta jest ściśle związana ze skutecznością prowadzenia walki w kickboxingu. Podsumowując, można stwierdzić, że proces treningowy zawodników kickboxingu startujących w rywalizacji na zasadach K1 powinien opierać się na wszechstronnym rozwoju motorycznym zawodnika w zakresie siły, szybkości i wytrzymałości oraz na utrzymywaniu optymalnej masy ciała.

Kolejnym aspektem realizacji Indywidualnego Planu Badawczego była analiza reakcji fizjologicznych zachodzących podczas realnej walki kickboxingu w formule K1, co opisano w artykule pt. *Physiological Responses and Bout Analysis in Elite Kickboxers During International K1 Competitions* (załącznik 4). Badania przeprowadzono podczas dwóch cykli ligi kickboxingu na zasadach K1. Analizie poddano wyniki pomiarów 15 kickboxerów reprezentujących wysoki poziom sportowy. Średnia wieku zawodników wyniosła $23,9 \pm 4,6$ lat. Badani uprawiali kickboxing średnio $9,9 \pm 5,3$ lat. W toku badań dokonano pomarów tętna za pomocą pulsometru Garmin Fenix 6 z zastosowaniem paska piersiowego oraz pomiaru stężenia mleczanu we krwi analizatorem Lactate Scout firmy SKF po pobraniu krwi z opuszka palców. Pierwszy pomiar wykonano w momencie gotowości do walki po rozgrzewce. Kolejne pomiary zostały wykonane bezpośrednio po pierwszej, drugiej i trzeciej rundzie pojedynku. Diagnozy dokonywano podczas jednominutowych przerw między rundami. Po zakończeniu pojedynku tętno monitorowano w warunkach regeneracji do uzyskania wartości wyjściowych, a stężenie mleczanu było mierzone 20 minut po zakończeniu walki. Badanie realizowano według poniższego schematu (rys. 1).

Pomiary fizjologiczne

↓

Pierwsza runda walki

↓

Pomiary fizjologiczne

↓

Druga runda walki

↓

Pomiary fizjologiczne

↓

Trzecia runda walki

↓

Pomiary fizjologiczne podczas regeneracji

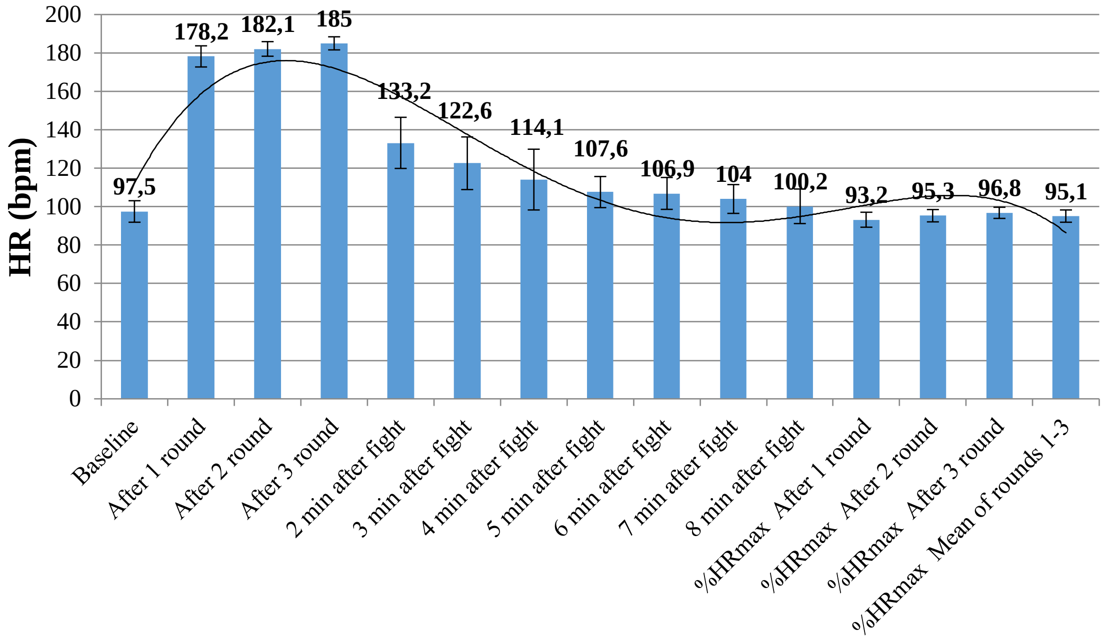
Rys. 1. Schemat badania

Na podstawie odnotowanych wartości tętna obliczony został wskaźnik skuteczności restytucji (SR).

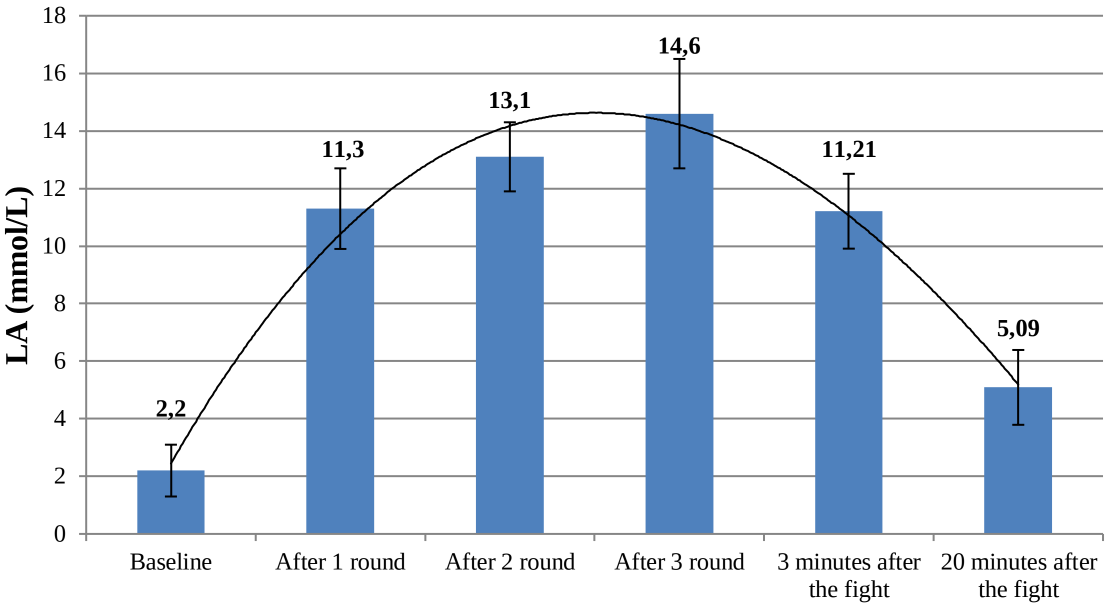
$$\mathbf{SR} = \frac{\mathrm{HR2} - \mathrm{HR3}}{\mathrm{HR2} - \mathrm{HR1}} x\ 100\%$$

gdzie: HR1 – tętno spoczynkowe,
HR2 – najwyższe wartość tętna odnotowana w całym pojedynku,
HR3 – tętno z piątej minuty restytucji.

Do oceny istotnych statystycznie różnic między pomiarami zastosowano analizę wariancji (Anova) z powtarzalnymi pomiarami. Natomiast istotność różnic między kolejnymi pomiarami zweryfikowano testem post-hoc Tukeya. Wybór testów uwarunkowany był spełnieniem założenia o zgodności rozkładu z rozkładem normalnym, który zweryfikowano testem Shapiro-Wilka. Wyniki wykazały, że walka wywołała silny stres fizjologiczny. Stwierdzono istotny wzrost tętna (f = 4 502,30 i p < 0,001) i stężenia mleczanu we krwi (f = 26,425 i p < 0,001). W trakcie walki częstość skurczów serca systematycznie się zwiększała, osiągając najwyższe wartości w ostatniej, trzeciej rundzie (185±3,4 sk·min^{-1}) (rys. 2). Podobnie najwyższe stężenie mleczanu odnotowano po trzeciej rundzie pojedynku 14,6 ± 1,9 mmol·L^{-1}, a po 20 minutach regeneracji wartość stężenia mleczanu okazała się wyższa niż w pierwszym pomiarze (rys. 3). Po zakończeniu walki częstość skurczów serca powróciła do wartości wyjściowych dopiero po 7 minutach regeneracji. Wskaźnik skuteczności restytucji w badanej grupie zawodników wyniósł średnio około 89,8% ± 10,4%. Z analizy wynika zalecenie, aby w toku przygotowania zawodników kickboxingu do rywalizacji na zasadach K1 stosować wysiłki o intensywności zbliżonej do maksymalnej lub submaksymalnej.



Rys. 2. Częstość skurczów serca w kolejnych pomiarach
Źródło:[47]



Rys. 3. Stężenie mleczanu w kolejnych pomiarach
Źródło: [47]

W kolejnym artykule, zatytułowanym *Evaluation of the Body Composition and Selected Physiological Variables of the Skin Surface Depending on Technical and Tactical Skills of Kickboxing Athletes in K1 Style* (załącznik 5) dokonano określenia składu ciała, a także pomiaru zmian temperatury i pH skóry, które zachodzą wskutek walki kickboxingu w formule K1; ponadto określono związek między badanymi parametrami a wskaźnikami wyszkolenia techniczno-taktycznego. Badaniu poddano 24 zawodników walczących w sześciu różnych kategoriach wagowych (–71kg, –75kg, –81kg, –86kg, –91kg, +91kg). Analiza składu ciała została przeprowadzona techniką bioimpedancji elektrycznej z wykorzystaniem analizatora Tanita BC 601. Temperaturę skóry mierzono profesjonalnym termometrem Skin-Thermometer ST 500. Pomiaru kwasowości powierzchni skóry dokonano przy użyciu Skin-pH-Meter PH 905. Pomiarów temperatury skóry oraz pH dokonywano w następujących miejscach: czoło, klatka piersiowa, ramię, dłoń, udo, podudzie, stopa. Wykonywano je przed walką oraz po pierwszej, drugiej i trzeciej rundzie pojedynków. Dodatkowo wszystkie walki zostały nagrane, a na podstawie zapisu cyfrowego dokonano obliczenia wskaźników wyszkolenia techniczno-taktycznego. Normalność rozkładu danych została sprawdzona i potwierdzona przy użyciu testu Shapiro-Wilka. Korelacje między dwiema zmiennymi o rozkładzie normalnym określono za pomocą korelacji liniowej Pearsona, natomiast dla zmiennych niespełniających kryterium rozkładu normalnego obliczono współczynnik korelacji rang Spermana. Zmiany temperatury oraz pH skóry w czasie oceniano za pomocą analizy wariancji (Anova Friedmana). Kickboxerzy, którzy rywalizują w niższych kategoriach wagowych, charakteryzują się m.in. wyższymi wskaźnikami przygotowania techniczno-taktycznego ($p<0,001$). W związku z tym można uznać, że skład ciała wpływa na poziom wskaźników wyszkolenia techniczno-taktycznego. Temperatura skóry zmieniała się z każdą rundą walki, a jej spadek odnotowano na dużych grupach mięśni (klatka piersiowa, ramię, udo) w miarę postępu walki ($p < 0,001$). Walka w kickboxingu według zasad K1 doprowadziła również do zmian pH skóry. Wyniki badań sugerują konieczność systematycznego monitorowania składu ciała. Analizowane komponenty wykazały związek z ocenianymi parametrami walki i poziomem wyszkolenia zawodników .

Kontynuując analizę walki w aspekcie fizjologicznym i biochemicznym, dokonano pomiarów równowagi kwasowo-zasadowej i saturacji krwi w odniesieniu do wskaźników wyszkolenia techniczno-taktycznego. Wyniki zostały opublikowane w artykule pt. *Acid–Base Balance, Blood Gases Saturation, and Technical Tactical Skills in Kickboxing Bouts according to K1 Rules* (załącznik 6). Badanie przeprowadzono na grupie 14 zawodników kickboxingu prezentujących wysoki poziom sportowy. Analiza parametrów równowagi kwasowo-zasadowej została dokonana przy użyciu gazometru EPOC (Siemens) bezpośrednio po pobraniu 95 µl krwi arterializowanej z opuszków palców do szklanych kapilar zawierających heparynę litową zbalansowaną wapniem (65 IU/ml). Oznaczenia wykonano 5 minut przed walką oraz 3 minuty i 20 minut po walce. Zmierzono stężenie jonów wodorowych (H+), ciśnienie parcjalne tlenu (pO2) i ciśnienie parcjalne dwutlenku węgla (pCO2), wyliczono nadmiar zasad w płynie zewnątrzkomórkowym (BEecf) oraz stężenie jonów wodorowęglanowych HCO3. Dodatkowo, na podstawie rejestru cyfrowego pojedynków, dokonano analizy wskaźników wyszkolenia techniczno-taktycznego. Do porównania wyników pomiarów powtarzalnych zastosowano test Anova Friedmana, natomiast jako test post-hoc zastosowano test Dunna. Do oceny zależności między wskaźnikami wyszkolenia techniczno-taktycznego a pomiarami gazometrycznymi wykorzystano korelację liniową Pearsona. Dystrybucja danych została sprawdzona przy wykorzystaniu testu Shapiro-Wilka. Badane wskaźniki biochemiczne zmieniały się istotnie w trakcie wysiłku i podczas regeneracji. Największe różnice zaobserwowano po drugim pomiarze (tabela 1).

Tabela 1. Poziom parametrów równowagi kwasowo-zasadowej w badanej grupie zawodników w trzech kolejnych pomiarach

Parameter	**Measurement**									**Friedman's ANOVA**		**Post-hoc (Dunn's test)**	Effect Size
	I (n=14)			II (n=14)			III (n=14)						
	M	Me	SD	M	Me	SD	M	Me	SD	Chi^2	p	I-II	I-II
H^+ (nmol/L)	37,9	37,0	3,3	54,0	49,0	9,8	41,1	40,0	3,9	22,29	<0,001	<0,05	0,80
pCO2 (mmHg)	37,2	37,3	3,3	31,8	31,9	2,6	35,2	35,0	0,7	7,43	0,024	<0,05	0,27
pO2 (mmHg)	77,2	75,2	6,0	85,6	85,1	8,5	73,9	75,8	4,5	16,15	<0,001	<0,05	0,58
HCO3- (mmol/L)	24,6	25,3	1,3	14,9	15,4	1,6	21,3	21,6	1,8	24,57	<0,001	<0,05	0,88
BE mmol/L	0,5	0,9	1,2	-11,9	-10,6	2,7	-3,7	-3,2	2,4	28,00	<0,001	<0,05	1,00
TCO2 (mmol/L)	24,1	25,1	1,3	15,8	16,1	1,4	21,5	21,7	1,1	24,50	<0,001	<0,05	0,88

Źródło: [45]

Analiza korelacji nie wykazała istotnych statystycznie zależności między wskaźnikami wyszkolenia techniczno-taktycznego a badanymi zmiennymi biochemicznymi. Zaburzenia w równowadze kwasowo-zasadowej oraz nasyceniu krwi tlenem i dwutlenkiem węgla wskazują, że zasadniczą rolę podczas walki kickboxingu na zasadach K1 odgrywa metabolizm beztlenowy. W związku z tym w toku szkolenia powinien być systematycznie wdrażany trening anaerobowy. Dodatkowo zawodnicy muszą charakteryzować się dobrą tolerancją kwasicy metabolicznej oraz zdolnością do skutecznej walki pomimo zaburzeń w równowadze kwasowo-zasadowej.

Określenie wskaźników przygotowania techniczno-taktycznego pozwala na przeprowadzenie kontroli trenerskiej na podstawie zapisu rejestru cyfrowego pojedynku. W związku z tym na potrzeby właściwych interpretacji wyników dokonano obliczenia wymienionych wskaźników dla trzech różnych kategorii zawodniczych. W artykule pt. *Indices of Technical and Tactical Training During Kickboxing at Different Levels of Competition in the K1 Formula* (załącznik 7) określono wskaźniki wyszkolenia techniczno-taktycznego dla zawodników reprezentujących różne poziomy zaawansowania startowego. Badaniu poddano zwycięzców wszystkich kategorii wagowych w turnieju lokalnym, mistrzostwach polski oraz mistrzostwach świata. Wyniki obserwacji poddano analizie statystycznej z wykorzystaniem testu Anova Kruskal-Wallisa w celu oceny różnic w trzech turniejach. Natomiast istotność różnic między poszczególnymi pomiarami zweryfikowano testem post-hoc Bonferroniego. Wyniki badań pokazują, że aktywność ataku podczas mistrzostw świata oscyluje na poziomie 145,37 pkt., podczas mistrzostw Polski 97,13 pkt. natomiast podczas turnieju lokalnego 60,62 pkt. Podobne tendencje występują w wartościach wskaźnika skuteczności i efektywności ataku. Określone wskaźniki wyszkolenia techniczno-taktycznego na różnych poziomach rywalizacji mogą służyć badaczom do wstępnych zestawień oraz interpretacji wskaźników na podstawie średnich wartości wykazanych w niniejszym badaniu. Opierając się na wynikach najlepszych zawodników, można wyznaczyć kierunki szkolenia słabszych adeptów w poszczególnych aspektach walki.

Ostatnim elementem niniejszej dysertacji było uzupełnienie analizy fizjologicznej walki kickboxingu na zasadach K1, którą opisano w artykule pt. *Determination of the Real Training Load Based on Monitoringo of K1 Kickboxing Bouts* (załącznik 8). W badaniu dokonano określenia obciążenia startowego, jakie zachodzi podczas walki kickboxingu w formule K1, monitorując tętno zawodników. Następnie indywidualnie dla każdego badanego obliczono tętno maksymalne według wzoru [50]:

$$\text{HRmax} = 202{,}5 - (0{,}53 * \text{wiek w latach})$$

W arkuszu kalkulacyjnym dokonano procentowego obliczenia wartości odnotowanych podczas walki w stosunku do tętna maksymalnego z powyższego wzoru. Rejestrowano tętno szczytowe podczas pierwszej, drugiej oraz trzeciej rundy walki. Istotność różnic między trzema pomiarami obliczono, stosując jednoczynnikową analizę wariancji (Anova) z powtarzalnymi pomiarami. Istotność różnic między poszczególnymi rundami (I a II, II a III, I a III) obliczono testem post-hoc Tukeya. Z każdą rundą u zawodników pojawiały się wyższe wartości tętna szczytowego, które okazały się istotne statystycznie (p<0,001) w silnym efekcie. Między pierwszą a drugą rundą oraz drugą i trzecią efekt był umiarkowany, a wartości istotne statystycznie p < 0,005 (tabela 2).

Tabela 2. Wartości tętna szczytowego odnotowane podczas walki

HR	Descriptive statistics										
	n	$\bar{x}$	**Min.**	**Max.**	**Q1**	**Q3**	**SD**	**p_1**	**p_2**	**ES_1**	**ES_2**
HR Peak 1 round	18	181,66	176,0	188,0	179,0	184,0	3,25	-	**0,003**	-	0,50
HR Peak 2 round	18	183,16	178,00	189,0	182,0	185,0	2,79	**0,003**	-	0,50	-
HR Peak 3 round	18	184,66	180,0	190,0	183,0	186,0	2,78	**<0,001**	**<0,001**	1,00	0,54
ANOVA	**p=0,00** ES=0,99										

Źródło: [51]

W pierwszej rundzie zawodnicy bazowali na 95,44% HRmax, w drugiej rundzie wartość ta zwiększyła się do 96,23%, natomiast w trzeciej do 97,01% HRmax. Wartości te były istotne statystycznie (p< 0,001) oraz przejawiały wysoki efekt.

8. Wnioski

1. Aktywność ataku badanych zawodników lokowała się na poziomie 99,93 pkt., żaden z zawodników nie przekroczył 198 pkt. Odpowiada to średnim wartościom wskaźnika nieznacznie wyższym, niż prezentują medaliści krajowi, natomiast niższym, niż uzyskiwali medaliści mistrzostw świata. Wyniki wskazują na możliwości poprawy rezultatów startowych w zakresie zwiększenia aktywności zawodnika w walce, a także na różnice indywidualne w stosunku do najlepszych zawodników.
2. Efektywność ataku badanych zawodników wyniosła średnio 50,74 pkt., żaden z zawodników nie przekroczył 76,14 pkt. Odpowiada to wartościom niższym niż średnio uzyskiwane przez mistrzów świata i kraju. Wyniki badań wskazują, że dzięki zwiększeniu efektywności ataku można uzupełnić braki w wyszkoleniu, a w konsekwencji wpłynąć na ostateczny rezultat walki. Przeprowadzona analiza sugeruje zatem trenerom kierunki rozwoju sportowego badanych zawodników.
3. Skuteczność ataku badanych zawodników mieściła się na poziomie 54,73 pkt., żaden z zawodników nie przekroczył 79 pkt. Odpowiada to wartościom niższym niż średnio uzyskiwane przez mistrzów świata i kraju, natomiast znacząco wyższym od ich minimalnych wartości obliczonych dla mistrzów Polski. Wyniki wskazują na możliwości poprawy precyzyjności wykonywanych technik.
4. Stosowanie wskaźników techniczno-taktycznych stanowi nowoczesny i efektywny sposób kontroli trenerskiej w zakresie analizy walki kickboxingu. Ponadto badania własne wskazują, że ocena poziomu wyszkolenia techniczno-taktycznego może ujawniać braki w przygotowaniu specjalnym zawodnika, a w efekcie zwiększyć jego możliwości startowe oraz przyczynić się do osiągnięcia sukcesu podczas rywalizacji w formule K1.
5. Występują istotne statystycznie różnice między wartościami wskaźników wyszkolenia techniczno-taktycznego a poziomem rywalizacji. Najwyższe wskaźniki osiągali zawodnicy rywalizujący na mistrzostwach świata, natomiast najniższe podczas turnieju lokalnego. Widoczne są różnice w średnich wartościach wskaźników między mistrzostwami świata i mistrzostwami kraju, jednak nie są one istotne statystycznie.

6. Analiza przewinień, jakich dopuszczali się badani zawodnicy, wskazuje, że najczęściej karaną czynnością był niedozwolony chwyt przeciwnika. W perspektywie ilościowej zawodnicy popełniali dwa uchybienia regulaminowe podczas walki. Warto zaznaczyć, że trzykrotne powtórzenie przewinienia skutkuje utartą punktu, co może wpłynąć na rezultat końcowy walki.
7. Nie występuje zależność między liczbą przewinień a wartością wskaźników przygotowania techniczno-taktycznego.
8. Najbardziej efektywną techniką ręczną okazał się cios sierpowy wysoki, natomiast z kategorii technik nożnych – kopnięcie okrężne wysokie.
9. Wyższą aktywność ataku przejawiali zawodnicy charakteryzujący się lepszymi wynikami w próbie tapping, skoku w dal z miejsca, teście Coopera, sile statycznej prawej dłoni oraz próbie zwinności.
10. Wyższą efektywność i skuteczność ataku przejawiali zawodnicy charakteryzujący się lepszymi wynikami w próbie tappingu, skoku w dal z miejsca, teście Coopera, sile statycznej obu dłoni, próbie zwinności oraz sile mięśni brzucha.
11. Wyniki badań własnych wskazują na zależność między sprawnością fizyczną a poziomem przygotowania techniczno-taktycznego zawodników.
12. Wyższa aktywność ataku istotnie koreluje z niższą masą ciała, procentową zawartością tłuszczu, masą mięśni, poziomem BMI, DCI oraz wiekiem metabolicznym. Dodatkowo na aktywność ataku istotnie wpływa wyższa zawartość wody w organizmie.
13. Wyższa efektywność ataku istotnie koreluje z niższą masą ciała, procentową zawartością tłuszczu, masą mięśni, poziomem BMI oraz wiekiem metabolicznym. Dodatkowo na efektywność ataku istotnie wpływa wyższa zawartość wody w organizmie.
14. Wyższa skuteczność ataku istotnie koreluje z niższą masą ciała, procentową zawartością tłuszczu, masą mięśni, poziomem BMI oraz wiekiem metabolicznym. Dodatkowo na efektywność ataku istotnie wpływa wyższa zawartość wody w organizmie.
15. Podczas walki kickboxingu w formule K1 występują istotne statystycznie zmiany w temperaturze skóry, zachodzące na czole, klatce piersiowej, ramieniu, dłoni, udzie i podudziu. Na wszystkich mierzonych obszarach z wyjątkiem dłoni odnotowano spadek temperatury w kolejnych rudach w stosunku do wartości bazowej.

16. Walka kickboxingu w formule K1 wywołuje narastające pocenie się, które mogło wpłynąć na odnotowane w kolejnych rundach zwiększenie pH skóry na mierzonych fragmentach kończyn górnych i dolnych.
17. Walka w kickboxingu w formule K1 wywołuje duży stres fizjologiczny, który wzrasta wraz z jej przebiegiem. Podczas pierwszej rundy zawodnicy osiągali średnią częstość skurczów serca 178,2 $sk \cdot min^{-1}$ przy poziomie stężenia mleczanu we krwi 11,3 $mmol \cdot L^{-1}$. W kolejnej rundzie częstość skurczów i stężenie mleczanu we krwi uległy zwiększeniu odpowiednio do 182,1 $sk \cdot min^{-1}$ i 13,1 $mmol \cdot L^{-1}$. Najwyższe wartości obu mierzonych parametrów odnotowano po trzeciej rundzie pojedynku (185,0 $sk \cdot min^{-1}$ oraz 14,6 $mmol \cdot L^{-1}$).
18. Badani zawodnicy charakteryzowali się bardzo dobrą skutecznością restytucji tętna, która wynosiła 89,8%. Świadczy to o wysokim poziomie wyszkolenia wytrzymałościowego.
19. Zaburzenia w równowadze kwasowo-zasadowej oraz zmiany w nasyceniu krwi tlenem i dwutlenkiem węgla obserwowane bezpośrednio po walce wskazują, że metabolizm beztlenowy odgrywa dużą rolę w walce kickboxingu w formule K1. Dodatkowo zawodnicy powinni charakteryzować się dobrą tolerancją kwasicy metabolicznej oraz zdolnością do kontynuacji wysiłku pomimo powstałych zaburzeń, a także wykazywać dobrą regenerację powysiłkową. Nie odnotowano związku równowagi kwasowo-zasadowej z wskaźnikami wyszkolenia techniczno-taktycznego.

9. Wnioski aplikacyjne

1. Wykorzystanie wskaźników aktywności, efektywności i skuteczności ataku może służyć programowaniu struktury rzeczowej i czasowej treningu kickboxerów.
2. Podczas treningu kickboxingu trenerzy powinni zwracać uwagę na konstruowanie kombinacji z wykorzystaniem ciosu sierpowego wysokiego oraz kopnięć okrężnych.
3. Podczas rywalizacji w formule K1 należy przestrzegać zawodników przed zbyt częstym przytrzymywaniem przeciwnika, aby nie dopuścić do utraty punktów w wyniku przewinienia.
4. Proces treningowy zawodników kickboxingu startujących w rywalizacji na zasadach K1 powinien opierać się na wszechstronnym rozwoju motorycznym zawodnika w zakresie rozwoju siły, szybkości i wytrzymałości oraz bazować na utrzymaniu optymalnej masy ciała.
5. W kickboxingu powinno się dokonywać systematycznych pomiarów składu ciała, gdyż wartości te mogą wpływać na przebieg walki oraz poziom umiejętności techniczno-taktycznych.
6. W treningu przygotowującym zawodników kickboxingu do rywalizacji według zasad K1 powinny dominować wysiłki o intensywności zbliżonej do maksymalnej lub submaksymalnej.
7. Trening beztlenowy powinien być włączony do procesu szkolenia kondycyjnego i siłowego, aby przygotować zawodników do fizjologicznych wymogów walki sportowej.

10. Piśmiennictwo

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11. Załączniki

1. Artykuł nr 1 pt. The Effectiveness of Kickboxing Techniques and its Relation to Fights Won by Knockout. *Arch. Budo* **2020**.
2. Artykuł nr 2 pt. Relation of Indicators of Technical and Tactical Training to Demerits of Kickboxers Fighting in K1 Formula. *Arch. Budo Sci. Martial Arts Extrem. Sport.* **2020**, *16*, 1–5.
3. Artykuł nr 3 pt. Physical Fitness and the Level of Technical and Tactical Training of Kickboxers. *Int. J. Environ. Res. Public Health* **2021**, *18*, 1–9.
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Załącznik nr 1

Ambroży, T.; Rydzik, Ł.; Kędra, A.; Ambroży, D.; Niewczas, M.; Sobiło, E.; Czarny, W. The Effectiveness of Kickboxing Techniques and its Relation to Fights Won by Knockout. *Arch. Budo* **2020**.

https://archbudo.com/view/abstract/id/13154 (dostęp 27.01.2023 r.)

ORIGINAL ARTICLE

The effectiveness of kickboxing techniques and its relation to fights won by knockout

Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Manuscript Preparation
E Funds Collection

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Received: 29 December 2019; **Accepted:** 21 January 2020; **Published online:** 17 February 2020

AoBID: 13154

Abstract

Background and Study Aim: Ratio of fights won is important to kickboxers on professional and amateur levels. Knockout is the most economical way of winning the fight. The objective of the paper is the effectiveness of kickboxing techniques and their impact on winning the fight by knockout.

Material and Methods: There were 156 participants in the study (61 amateurs and 95 professionals). Their total number of fights won by knockout was 188 and the amateur competitions they participated in complied with the K-1 ruleset. Fighters were 19 to 32 years old and their training experience was on the average 7.36 yrs. ±3.24 yrs. The shortest training lasted 3 yrs. and the longest one 18 yrs. The study was conducted using the analysis of videos of professional fights as well as diagnostic survey conducted in a group of amateur fighters. The survey included questions about training experience and techniques used in a fight won by knockout. The video analysis also included the techniques used in a fight won by knockout.

Results: *Hook high* and *roundhouse kick high* were the most effective kickboxing techniques in winning fights by knockout. The comparison of techniques used in a knockout between amateur and professional fighters did not bring any statistically significant differences. It was shown however that professional fighters used the most effective techniques: more often than amateurs.

Conclusions: During the training the fighters should pay special attention to constructing combinations of punches and kicks using *hook high* and *roundhouse kick high* techniques. Using proper techniques as well as numerous repetitions of the most effective techniques should be a part of any training of a kickboxing fighter.

Key words: amateur fighters • kicks • professional fighters • punches

Conflict of interest: Authors have declared that no competing interest exists

Ethical approval: The study was approved by the Ethics Committee at the regional medical chamber in Krakow number: 309/KBL/OIL/2019

Provenance & peer review: Not commissioned; externally peer-reviewed

Source of support: The research was supported from the funds of College of Medical Sciences, Institute of Physical Culture Studies, University of Rzeszow, Poland

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Knockout – *noun* **1.** (*in boxing*) a punch that knocks an opponent down for a count of ten and so wins a contest **2.** A sports competition in which a person or team beaten in one game or match is eliminated from the entire competition [25].

Kick – *verb* **1**. to strike a ball with the foot **2.** to strike something or somebody with the foot, e.g. in martial arts **3.** to make a thrashing movement with the legs, e.g. when fighting or swimming **4.** (*in cricket*) to bounce up high and quickly [25].

Kick – *noun* **1.** a blow with the foot, e.g. in martial arts **2.** a thrashing movement with the leg when swimming **3.** the striking of a ball with the foot [25].

Roundhouse kick – a type of kick executed into three height zones (low, middle, high) by the change position in the hip joint.

Punch *verb* to strike someone or something with the fist, e.g. in boxing or martial arts [25].

Fighter – *noun* a competitor in a full-contact sport such as boxing or taekwondo [25].

Technique– *noun* a way of performing an action [25].

Tactics – *plural noun* the art of finding and implementing means to achieve immediate or short-term aims [25].

Skill – *noun* an ability to do perform an action well, acquired by training [25].

INTRODUCTION

Kickboxing is a combat sport where two types of fights occur: light-contact and full contact. There is no limitation on the strength of kicks and punches in the latter type. Full contact kickboxing has a number of different rulesets such as: full contact (or American kickboxing), Low Kick or K-1 [1]. Fighters competing in this type of sports have a number of possible events both in amateur or professional level. The best fighters collect the titles and have a good ratio of the fights won. Depriving the competitor the possibility of continuing the fight (aka knockout) is the most economical way of ending the fight. It is also a spectacular show of fighter's skills [2]. The quick ending of a fight can be achieved by both punching or kicking techniques. The adequate launching of attack requires mastering of techniques as well as proper flexibility and perfect fitness [3]. Comprehensive movement and adjusting the tactics to competitor's skills are priorities [4]. Kickboxing techniques include kicks and punches according to the rules [5]. Punches include jabs, crosses and hooks, flying punches or spinning back-fists. Kicks used in the fight include front kicks, side kicks, roundhouse kicks, axe kicks, heel kicks and knee kicks [6]. The effectiveness of the attack depends not only on mastering the technique but also strength, velocity and endurance of the combatant. Psychological aspects as well as proper motivation of the fighters are also very important. On particular occasions (like during the fight) fighters can behave aggressively, which is quite often [7].

To develop a solid training plan for a kickboxer it is necessary to use own experience resulting from the analysis of a sport combat and the effectiveness of used techniques. To assess and analyse the fight a regular observation, which gives information on the level of mastering the fight techniques, is necessary. The level of technical skills used in a fight and the level of fitness matching the model characteristic of a kickboxing fight are assessed. The necessary data are collected by monitoring of the most effective techniques used in a fight, their value in the final scoring and their impact on the result of the fight.

Studies done during World Championships in kickboxing in 2009 and 2011 proved that jabs are the most common punches while roundhouse kicks were the most common kicks [8]. Other study concerning professional mixed martial arts fighters proved that knockout was usually a result of a direct fist hit on the head [9]. Analysis of 40 boxing bouts proved the hooks were most common punches [10]. Another analysis of boxing fights proved that hooks were most common punches and uppercuts were the best scoring punches [11]. Machado et al. [12] analysed the strength of kicks of kickboxing and taekwondo fighters. The results proved similar strength of kicks in fighters of both combat sports [12]. A study of elite karate fighters proved that punching techniques were much more effective than kicking ones. Moreover the duration of an attack in a karate fight was assessed. It was equal to less than 2 seconds on average [13].

The objective of the paper is the effectiveness of kickboxing techniques and their impact on winning the fight by knockout.

MATERIAL AND METHODS

There were 156 participants in the study (61 amateurs and 95 professionals). Their total number of fights won by knockout was 188 and the amateur competitions they participated in complied with the K-1 ruleset. Fighters were 19 to 32 years old and their training experience was on the average 7.36 yrs. ±3.24 yrs. The shortest training lasted 3 yrs. and the longest one 18 yrs.

The training experience of the half of the participants was at least 6 years. Fighters who took part in European Championship as the most prestigious event they participated in had the longest training experience (8.67 yrs. ±1.72 yrs.). Subsequentially fighters participating in Polish Championships had the training experience of 7.75 yrs. ±5.13 yrs. and those participating in World Championships had 6.55 yrs. ±1.4 yrs. 29 fighters (47.5% of the respondents) participated in World Championships, 12 fighters (19.7% of the respondents) participated only in European Championships and 20 fighters (32.8% of the respondents) participated only in Polish Championships (Table 1).

The video analysis of 95 professional fights complying with the K-1 ruleset which ended with knockout was made. The study included fight in the following federations: Glory, K1 World Grand Prix, DSF Kickboxing Challenge and HFO. The results of the study and the video analysis were compared.

Table 1. Training experience (2013-2019).

Kind of experience training	Statistics indicators								
	n	%	$\bar{x}$	Me	Min.	Max.	Q1	Q3	SD
World Championships	29	47.5	6.55	6.00	6.00	10.00	6.00	6.00	1.40
European Championships	12	19.7	8.67	8.00	7.00	12.00	7.50	9.00	1.72
Polish Championships	20	32.8	7.75	4.00	3.00	18.00	4.00	12.50	5.13
Total	61	100.0	7.36	6.00	3.00	18.00	6.00	9.00	3.24

Statistical Analysis

The statistical analysis of the collected data was conducted with the use of Statistica 13.1 by StatSoft. The two-sided significance test of structural indicators was used to compare number and percentage of fights won by knockout using different techniques to determine whether some of them occurred more or less often than others. Spearman's test was used to assess the relation between two numerical variables (training experience and numbers of fights won by knockout) and test was used to assess the differences in the distribution of the qualitative data in two groups. The tests used in the analysis were non-parametric. They were chosen because the distributions of studied variables were not normal (verified with Shapiro-Wilk test).

The basic statistical description included: number of observations (n); mean ($\bar{x}$); median (Me); minimum (Min.); maximum (Max.); lower quartile (Q1); upper quartile (Q3); standard deviation (SD or ±). The level of statistical significance was set at $p<0.05$.

Table 2. The frequency of winning the fight by knockout using some kickboxing techniques in the groups of amateur and professional fighters.

Kickboxing techniques	Amateurs (n =61)		Professionals (n = 95)		Total	
	n	%	n	%	n	%
Jumping kick	0	0.0	1	1.1	1	0.4
Side kick middle	0	0.0	1	1.1	1	0.4
Jumping punch	3	1.6	0	0.0	3	1.1
Axe kick	5	2.7	0	0.0	5	1.8
Roundhouse kick middle	0	0.0	5	5.3	5	1.8
Heel kick	2	1.1	5	5.3	7	2.5
Knee kick middle	6	3.2	3	3.2	9	3.2
Front kick high	8	4.3	3	3.2	11	3.9
Side kick high	9	4.8	2	2.1	11	3.9
Front kick middle	11	5.9	1	1.1	12	4.2
Chop high	7	3.7	6	6.3	13	4.6
Back fist	11	5.9	4	4.2	15	5.3
Chop middle	17	9.0	1	1.1	18	6.4
Roundhouse kick low	18	9.6	3	3.2	21	7.4
Turning kick middle	15	8.0	6	6.3	21	7.4
Punch high	14	7.5	8	8.4	22	7.8
Roundhouse kick high	26	13.8	15	15.8	41	14.5
Hook high	36	19.2	31	32.6	67	23.7
Total	188	100.0	95	100.0	283	100.0
p	**$\chi^2(17) = 43.59$ $p<0.001$**					

RESULTS

The training experience was not a statistically significant factor influencing the number of fights won by knockout (Spearman correlation 0.16; p = 0.205).

All studied competitors had flexibility sufficient to using high kicks. The total number of fights won by knockout according to K-1 rulesets was 188. The study was compared to 95 professional fights organized by most popular kickboxing federations.

The kickboxing techniques were arranged from the least to the most often used (for both amateur and professional fighters) when finishing the fight with a knockout. In the amateur group *heel kick* was the least often (2 times 1.1%) and *hook high* was the most often (36 times 19.2%) used to win the fight by knockout. Other effective techniques included *roundhouse kick high* (26 times 13.8%), *roundhouse kick low* (18 times 9.6%) and *chop middle* (17 times 9.0%). Amateur fighters have never used *jumping kick*, *side kick middle* or *roundhouse kick middle* to win the fight by knockout. In the professional group *jumping kick*, *side kick middle* and *roundhouse kick middle* were the least often used techniques (1 time 1.1%) of winning by knockout. *Hook high* was the most often used technique (31 times 32.6%). Other effective techniques in this group included *roundhouse kick high* (15 times 15.8%) and *punch high* (8 times 8.4%). Professional fighters have never used *jumping punch or axe kick* to win the fight by knockout. Most of the differences in frequencies of using different techniques occurred for less often used techniques. Despite the fact that *hook high* was the most often used technique in both groups, it was used almost twice as many more often in the group of professional fighters than in the group of amateur competitors (32.6% vs. 19.2%). Types of techniques used to win the fight by knockout differed significantly in both groups (Table 2).

In the tables below (Table 3 and Table 4) the statistical significance of the differences in frequencies of winning by knockout with the use of different techniques was computed for both groups separately in order to find out whether some techniques are more or less effective than others. It was proven that the differences are not statistically significant in neither group (p>0.05).

Table 3. Significance of the differences in the frequencies of winning fights by knockout when using different techniques in the group of amateur fighters (n = 61).

Kickboxing techniques	*Heel kick*	*Jumping punch*	*Axe kick*	*Knee kick middle*	*Chop high*	*Front kick high*	*Side kick high*	*Back fist*	*Front kick middle*	*Punch high*	*Turning kick middle*	*Chop middle*	*Roundhouse kick low*	*Roundhouse kick high*
Heel kick														
Jumping punch	0.309													
Axe kick	0.738													
Knee kick middle	0.873	0.347	0.652											
Chop high	0.397	0.292	0.840	0.758										
Front kick high	0.708	0.445	0.859	0.660	0.763									
Side kick high	0.400	0.292	0.840	0.758	1.000	0.760								
Back fist	0.548	0.581	0.459	0.635	0.486	0.545	0.486							
Front kick middle	0.799	0.296	0.917	0.696	0.917	0.806	0.917	0.463						
Punch high	0.734	0.518	0.848	0.697	0.777	0.959	0.777	0.603	0.810					
Turning kick middle	0.957	0.319	0.708	0.914	0.834	0.691	0.834	0.574	0.763	0.721				
Chop middle	0.702	0.359	0.919	0.635	0.783	0.922	0.783	0.481	0.846	0.896	0.679			
Roundhouse kick low	0.832	0.364	0.627	0.957	0.722	0.645	0.722	0.670	0.665	0.685	0.872	0.615		
Roundhouse kick high	0.717	0.333	0.958	0.640	0.808	0.888	0.808	0.467	0.879	0.871	0.689	0.958	0.617	
Hook high	0.766	0.304	0.957	0.672	0.877	0.831	0.877	0.459	0.958	0.828	0.733	0.880	0.643	0.917

Table 4. Significance of the differences in the frequencies of winning fights by knockout when using different techniques in the group of professional fighters (n = 95).

Kickboxing techniques	*Jumping Kick*	*Side Kick Middle*	*Front Kick Middle*	*Chop Middle*	*Side Kick High*	*Knee Kick Middle*	*Front Kick High*	*Roundhouse Kick Low*	*Back Fist*	*Roundhouse Kick Middle*	*Heel Kick*	*Chop High*	*Turning Kick Middle*	*Punch High*	*Roundhouse Kick High*
Jumping kick	-														
Side kick middle	1.000	-													
Front kick middle	1.000	1.000													
Chop middle	1.000	1.000	-												
Side kick high	0.908	0.908	0.908	0.908	-										
Knee kick middle	0.879	0.879	0.879	0.879	0.941	-									
Front kick high	0.879	0.879	0.879	0.879	0.941	1.000	-								
Roundhouse kick low	0.879	0.879	0.879	0.879	0.941	1.000	1.000	-							
Back fist	0.838	0.838	0.838	0.838	0.895	0.945	0.945	0.945	-						
Roundhouse kick middle	0.800	0.800	0.800	0.800	0.851	0.889	0.889	0.889	0.938	-					
Heel kick	0.800	0.800	0.800	0.800	0.851	0.889	0.889	0.889	0.938	1.000	-				
Chop high	0.770	0.770	0.770	0.770	0.817	0.844	0.844	0.844	0.886	0.943	0.943	-			
Turning kick middle	0.770	0.770	0.770	0.770	0.817	0.844	0.844	0.844	0.886	0.943	0.943	1.000	-		
Punch high	0.716	0.716	0.716	0.716	0.757	0.763	0.763	0.763	0.788	0.833	0.833	0.882	0.882	-	
Roundhouse kick high	0.574	0.574	0.574	0.574	0.602	0.562	0.562	0.562	0.544	0.547	0.547	0.559	0.559	0.617	-
Hook high	0.349	0.349	0.349	0.349	0.365	0.288	0.288	0.288	0.240	0.211	0.211	0.190	0.190	0.172	0.229

DISCUSSION

The assessment of the effectiveness of techniques of kickboxing in winning by knockout did not show statistically significant differences between the different techniques neither in the group of amateur nor in the group of professional fighters. The most popular techniques used in winning the fight by knockout were hook *high punch* and *roundhouse high kick*. The effectiveness of both techniques results from a direct hit on the head which causes loss of balance because of probable hit of the brain on the skull [15]. Chronic traumatic brain injury or encephalopathy was considered by the experts to be the most serious health problem in modern boxing [16]. According to the analysis of the distribution of punches of heavyweight boxers the knockout was mostly caused by chop high punch directed into the head [17]. Lystad [18] conducted a study diagnosing the most common traumas in kickboxing. The results of his study showed that the head is the part of a body exposed the most to punches and kicks which cause numerous traumas [18]. Garland et al. [19] who studied muay thai and kickboxing fighters came to similar results. The video analysis of mixed martial arts fights of elite federation UFC proved that all knockouts were caused by a direct hit on the head, the most often on the jaw [20]. Garcia et al. [21] assessed the strength of handshakes of boxers and proved that the strength of the upper limbs is well developed which can result in high effectiveness of winning the fight by knockout. During the training and the kickboxing fight itself punches play a key role and that is why the strength of the upper limbs should be developed above average.

According to own study *roundhouse kick low* (9.6%) and *chop middle* (9.0%) were also effective in winning the fight by knockout. Low kicks are mostly directed at thigh muscles and the knockout is often caused by often repeated hitting the same place. Numerous hits can cause the loss of balance because the lower limb is no longer able to carry the body. The analysis of traumas in contact karate proved that 35% of the traumas in the lower limbs are caused by numerous kicks on the same place [22]. The kicking techniques are also very effective also in taekwondo, studies show that the effectiveness of the kick results from the appropriate strength of the thigh muscles [23]. The effectiveness of *chop middle* can be a result of a clean hit on the liver which is closely connected to autonomic nervous system. The effectiveness of the punch is additionally increased by the location of the organ which is not guarded by the ribs [24]. This may also be a reason why 8% of the fights ended by knockout were a result of a *turning kick middle* which was directed at the liver or the celiac plexus.

There were also some knockouts caused by *punch high* and *back fist*. Both techniques when used properly are very strong hits directed at the head. *Back fist* is also preceded by a turn which additionally increases the strength of the hit. *Front kick middle* directed at the liver or the celiac plexus was equally effective as *back fist*. Also *side kick*, *knee kick*, *axe kick*, *jumping punch* and *heel kick* had more than 5% of frequency in winning the fight by knockout.

CONCLUSIONS

The analysis of the study showed that the knockout was the most often caused by a hit on the head. That was the reason of high effectiveness of techniques such as *roundhouse kick high* or *hook high*. Moreover techniques directed at the stomach and thigh were also effective in winning the fight by knockout. The least effective techniques included *heel kick* and *jumping punch*.

The comparison of techniques used in a knockout between amateur and professional fighters did not bring any statistically significant differences. It was shown however that professional fighters used the most effective techniques: *hook high* and *roundhouse kick high* more often than amateurs. Especially in the case of the former of the two techniques the difference in the frequency of winning the fight by knockout was 32.6% to 19.2% in favour of professional fighters. Relatively small number of studied fights could be the reason for a lack of statistical significance of observed differences.

The study shows that during the training the fighters should pay special attention to constructing combinations of punches and kicks using *hook high* and *roundhouse kick high* techniques. Using proper techniques as well as numerous repetitions of the most effective techniques should be a part of any training of a kickboxing fighter.

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Cite this article as: Ambroży A, Rydzik Ł, Kędra A et al. The effectiveness of kickboxing techniques and its relation to fights won by knockout. Arch Budo 2020; 16: 11-17

Załącznik nr 2

Rydzik, Ł.; Niewczas, M.; Kędra, A.; Grymanowski, J.; Czarny, W.; Ambroży, T. Relation of Indicators of Technical and Tactical Training to Demerits of Kickboxers Fighting in K1 Formula. *Arch. Budo Sci. Martial Arts Extrem. Sport.* **2020**, *16*, 1–5.

https://smaes.archbudo.com/view/abstract/id/13629 (dostęp 27.01.2023 r.)

ORIGINAL ARTICLE
SCIENCE OF MARTIAL ARTS

Relation of indicators of technical and tactical training to demerits of kickboxers fighting in K1 formula

Authors' Contribution:
A Study Design
B Data Collection
C Statistical Analysis
D Manuscript Preparation
E Funds Collection

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Received: 06 November 2019; **Accepted:** 20 December 2019; **Published online:** 20 January 2020

AoBID: 13629

Abstract

Background and Study Aim: Breaking rules in combat sports can finally result in getting lower score that has an impact on the outcome of a bout. Currently there are no papers dealing with demerits in kickboxing. The objective of the paper was knowledge about demerits of the regulations occurred during amateur kickboxing bouts in K1 formula.

Material and Methods: Thirty one bouts were videotaped and 31 kickboxers were evaluated. Based on computed indicators (activeness, efficiency and effectiveness of the attack) the relation between the number of demerits and the indicators of technical and tactical training was searched.

Results: The most common demerit was forbidden holds of the rival (it concerned 13 (41.9%) competitors and it was 31.7% of all demerits). Competitors made on average 1.32 demerits. The effectiveness of the attack was on average 46.63 points, activeness of the attack was on average 91.61 points, efficiency of the attack was on average 60.16 points.

Conclusions: The largest group of competitors had 2 demerits in a bout. The largest number of demerits in a bout was 3. Forbidden holding was the most common demerit of kickboxers in K1 formula. Effectiveness, activeness and efficiency of the attack were on a high level and were not connected to the number of demerits in a bout.

Key words: activeness • competitors' offenses • effectiveness • efficiency • fair play

Conflict of interest: Authors have declared that no competing interest exists

Ethical approval: The study was approved by the local Ethics Committee

Provenance & peer review: Not commissioned; externally peer reviewed

Source of support: Departmental sources

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Technique– *noun* a way of performing an action [21].

Tactics – *plural noun* the art of finding and implementing means to achieve immediate or short-term aims [21].

Efficiency – *noun* **1.** the ability to make a physical movement with a minimum of unnecessary effort **2.** a comparison of the effective or useful output to the total input in any system [21].

Disqualification – *noun* the state of being disqualified from competition [21].

Muay Thai – *noun* a martial art that is a form of kickboxing, practiced in Thailand and across Southeast Asia [21]

INTRODUCTION

A kickboxing bout in K1 formula quite often causes a fighter to lose control over his physical possibilities. An important role during a bout is played by referees who monitor the course of the fight. Breaking sports regulations becomes more common in modern sports. Competitors often lose the match due to not complying with the rules. In combat sports such behaviour finally results in getting lower score that has an impact on the outcome of a bout. Assessment of the most often committed demerits will allow coaches to warn their competitors against actions which are negatively received by referees. This should protect the competitors against the loss of possible points or against disqualification.

Behaviour of this type does not have to be intentional, in most cases they are caused by lack of strength, disorientation or excessive stress. According to current regulations of World Association of Kickboxing Organizations a bout in K1 formula has many restrictions: elbow punches, head pulling during knee kicks, long-lasting clinches and kicking below thigh are forbidden. Currently there are no papers dealing with demerits and penalties in kickboxing. Existing analyses of a kickboxing bout are dealing with physiological indicators [1-4] or psychological aspects of success and proper motivation to achieving one's goals [5, 6]. Motarca [7] described fair play rules and enforcing regulations in order to improve sports ethics. Assessment of demerits and penalties was analysed in judo bouts. The analyses resulted in determining the influence of penalties on the efficiency of the competitors [8-10]. The analysis of the regulations of a kickboxing match is referred to the impact of new regulations on the general image of a sports fight [11]. Similar analyses were done for taekwondo and karate [12, 13]. However there are no comprehensive listings showing specific breaking the regulations by kickboxers fighting in the most popular formula of this sport which currently is K1.

The objective of the paper was knowledge about demerits of the regulations occurred during amateur kickboxing bouts in K1 formula.

MATERIAL AND METHODS

Thirty one bouts were videotaped and 31 kickboxers were evaluated. All bouts took place during the Polish Championship in K1 formula, which is the most important kickboxing event in Poland. The bouts regulations were based on the rules of WAKO (World Association of Kickboxing Organizations). All demerits of the fighters noticed by referees were specified. Additionally indicators of technical and tactical training (i.e. activeness of the attack, efficiency of the attack and effectiveness of the attack) of each competitor were computed. The indicators (in points score) were computed with the use of formulas specified in literature [14] and modified to the fight of kickboxing in K1 formula.

1. Efficiency of the attack (Sa)

$$Sa = \frac{n}{N}$$

n – number of effective attacks (every effective attack in K1 formula scores 1 pt.)
N – number of bouts

2. Effectiveness of the attack (Ea)

$$Ea = \frac{\text{number of effective attacks}}{\text{number of all attacks}} \text{ x } 100$$

* An effective attack is a technical action that is awarded a point
* An attack is any attempt of an offensive action

3. Activeness of the attack (Aa)

$$Aa = \frac{\text{number of all attacks}}{\text{number of all bouts}}$$

Statistical analysis

Based on computed indicators the relation between the number of demerits and the indicators of technical and tactical training was searched. To analyse the relations Pearson's linear correlation test and Spearman's rank correlation test were used. The level of significance was chosen at $p<0.05$. The data was analysed using Statistica 13.1 software by StatSoft Power Solutions, Inc. (Tulsa, USA).

RESULTS

The most common demerit was forbidden holds of the rival (it concerned 13 (41.9%) competitors and it was 31.7% of all demerits). Consecutive ones were the following: pulling head during knee kick, attacking after stop signal, holding rival's leg after his front kick, kick in the groin

Table1. Competitors' demerits in decreasing and alphabetic order.

Demerits	Related to competitor		Related to all demerits	
	n	%	n	%
Forbidden hold	13	41.9	13	31.7
Attacking after stop signal	3	9.7	3	7.3
Holding rival's leg after his front kick	3	9.7	3	7.3
Kick in the groin	3	9.7	3	7.3
Pulling head during knee kick	3	9.7	3	7.3
Double knee kick during one holding	2	6.5	2	4.9
Excessive rotating	2	6.5	2	4.9
Forbidden techniques on the thigh	2	6.5	2	4.9
Intentional fall	2	6.5	2	4.9
Punching with the interior part of the glove during hook punch	2	6.5	2	4.9
Spitting out the mouth guard	2	6.5	2	4.9
Attacking the back of the head	1	3.2	1	2.4
Elbow punch	1	3.2	1	2.4
Kicking in the back	1	3.2	1	2.4
Pushing the rival	1	3.2	1	2.4
Total	**41**	**132.5**	**41**	**100**

(they concerned 3, 9.7% competitors each and they were 7.3% of all demerits each). Double knee kick during one holding, intentional fall, spitting out the mouth guard, excessive rotation, punching with the interior part of the glove during hook punching, forbidden techniques on the thigh concerned 2 (6.5%) competitors each and they were 4.9% of all demerits each. Kicking in the back, elbow punch, attacking the back of the head and pushing the rival occurred to 1 (3.2%) competitor each and they were 2.4% of all demerits each (Table 1).

Table 2. Number of demerits in 31 kickboxers competitors.

Number of demerits	Competitors	
	n	%
None	8	25.8
1	8	25.8
2	12	38.7
3	3	9.7
Total	**31**	**100**

Twelve competitors (38.7%) had 2 demerits each, 8 (25.8%) had one and 8 (25.8%) had no demerits. 3 competitors (9.7%) had 3 demerits each (Table 2).

Competitors on average 1.32 demerits, the median was 1, minimum value 0, maximum value 3 lower quartile 0.00, upper quartile 2.00, and standard deviation 0.98.

The effectiveness of the attack was graded on average as 46.63 ±11.15 points (range 22 to 76.14), activeness of the attack was on average 91.61 ±22.86 (range 44 to 144). Efficiency of the attack was on average 60.6 ± 6.81 (range 43.0 to 71.0) (Table 3).

Statistically significant relations between the number of demerits and effectiveness, activeness and efficiency of the attack were not confirmed (Table 4).

DISCUSSION

The most common demerit of the participants in the study was forbidden holding of the rival, where competitors had to be separated by the referee.

Table 3. Effectiveness, activeness and efficiency of the attack

Variable	Statistics indicators							
	n	$\bar{x}$	Me	Min.	Max.	Q1	Q3	SD
Effectiveness (Ea)	31	46.63	45.23	22.00	76.14	41.10	53.60	11.15
Activeness (Aa)	31	91.61	92.00	44.00	144.00	73.00	107.00	22.86
Efficiency (Sa)	31	60.16	61.00	43.00	71.00	58.00	65.00	6.81

n: number of observations, $\bar{x}$**:** arithmetic mean, **Me:** median, **Min.:** minimum, **Max.:** maximum, **Q1:** lower quartile, **Q3:** upper quartile, **SD:** standard deviation

Table 4. Pearson's linear correlation coefficient (r) and testing probability (p) between the number of demerits vs. effectiveness, activeness and efficiency of the attack.

Relations between variables	r	p
Number of demerits vs. effectivity	−0.09	0.631
Number of demerits vs. activeness	−0.04	0.829
Number of demerits vs. efficiency	0.00	0.987

Excessive use of forbidden holds can be specific kind of defence or resting during the fight. Similar behaviour is characteristic for boxers, who during their fights often use clinching [15]. Another demerit was pulling the head during knee kick. This regulation was introduced relatively soon and that could be the reason why competitors may just use a locomotor habit which is very common during a sparring match. Pulling the head additionally increases efficiency and strength of the kick [16]. Attacking the rival after the stop signal given by the referee can be a result of aggression and some kind of rage that can be present while competitors exchange blows [17]. Holding rival's leg after his front kick is allowed in *muay thai* and it is usually followed by sweep [18]. Many competitors in kickboxing events come from *Thai boxing* and that is why this particular demerit can be a result of a locomotor habit, similarly to multiple knee kicks during one hold.

There were also some kicks in the groin that caused a break in the bout. This type of demerits occurs mostly when a competitor tries to give a low kick in the interior part of the thigh [19]. Analysis of bouts also allowed to see intentional causing breaks in a fight, particularly during defensive actions. This category of demerits include intentional falling or stumbling or spitting out the mouth guard. There were also forbidden techniques on the thigh which are allowed in karate, so they be a result of previous style of fighting of a competitor [20]. Elbow punch, which could be intentional, was the most drastic regulatory offense. Among rarely occurred offenses we can name kicks in the back or blows in the back of the head. They could be a result of a dynamic fight and quick moving of competitors. Statistically significant relations between the number of demerits and effectiveness, activeness and efficiency of the attack were not confirmed. The indicators of technical and tactical training in K1 formula of kickboxing are high and not connected to number of demerits of kickboxers. The analysis showed also relatively low number of demerits which can indicate high level of fair play in kickboxing bouts in K1 formula.

CONCLUSIONS

Based on the results of the study it can be stated that: the largest group of competitors had 2 demerits in a bout; the largest number of demerits in a bout was 3; forbidden holding was the most common demerit of kickboxers in K1 formula; effectiveness, activeness and efficiency of the attack were on a high level and were not connected to the number of demerits in a bout.

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Cite this article as: Rydzik Ł, Niewczas M, Kędra A et al. Relation of indicators of technical and tactical training to demerits of kickboxers fighting in K1 formula. Arch Budo Sci Martial Art Extreme Sport 2020; 16: 1-5

Załącznik nr 3

Rydzik, Ł.; Ambroży, T. Physical Fitness and the Level of Technical and Tactical Training of Kickboxers. *Int. J. Environ. Res. Public Health* **2021**, *18*, 1–9, doi:10.3390/ijerph18063088.

https://www.mdpi.com/1660-4601/18/6/3088 (dostęp 27.01.2023 r.)

International Journal of
Environmental Research and Public Health

MDPI

Article

Physical Fitness and the Level of Technical and Tactical Training of Kickboxers

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Abstract: Background: Kickboxing is a dynamically progressing combat sport based on various techniques of punches and kicks. The high level of physical fitness underlies the optimal development of technique in the competitors. The objective of this study was the assessment of the level of fitness of kickboxers and the relationships between fitness and technical and tactical training. Methods: The study included 20 kickboxers aged 18–32 demonstrating the highest level of sporting performance. Their body mass ranged from 75 to 92 kg and their height from 175 to 187 cm. The selection of the group was intentional, and the criteria included training experience and the sports level assessed by the observation of the authors and opinion of the coach. The level of fitness was evaluated with the use of selected trials of International Committee on the Standardization of Physical Fitness Tests and Eurofit tests. Aerobic capacity was tested and indicators of efficiency, activeness and effectiveness of attacks were calculated. Results: A significant correlation between the indicators of technical and tactical training and results of fitness tests was shown. Conclusions: There exists a correlation between efficiency, activeness and effectiveness of attacks and the speed of upper limbs, explosive strength, static strength of a hand, agility, VO_2max and abdominal muscle strength.

Keywords: physical fitness; technical and tactical indicator; kickboxing

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Citation: Rydzik, Ł.; Ambroży, T. Physical Fitness and the Level of Technical and Tactical Training of Kickboxers. *Int. J. Environ. Res. Public Health* **2021**, *18*, 3088. https://doi.org/10.3390/ijerph18063088

Academic Editors: Veronique Billat and Paul B. Tchounwou

Received: 7 February 2021
Accepted: 13 March 2021
Published: 17 March 2021

1. Introduction

General physical fitness is the locomotor basis on which a competitor can develop their professional techniques. There are a variety of different techniques in kickboxing which can be combined [1]. However, a proper level of technical and tactical training is the most important element of a competitor's success. Technical and tactical actions allow effective control in a bout and can almost entirely avoid a rival's attacks, simultaneously using offensive actions (counterattacks) [2]. Timing plays a key role, as it allows conducting an effective attack while simultaneously avoiding a rival's offensive actions [3]. Kickboxing is a combat sport in which competitors fight each other using kicks and punches [4]. Amateur fighters use protectors, which reduce trauma occurrence in fights [5]. There are many types of kickboxing (point fighting, light contact, kicklight, full contact, low kick) that have different rules. There are also many kickboxing organizations. The World Association of Kickboxing Organizations (WAKO) is the largest and the most significant of them [5].

Proper functioning of the cardiovascular system is the basis of the physical fitness of a kickboxer [6], which allows repeating highly intense actions during a whole fight, mainly because of the increase in the regeneration process [7]. Mean values of VO_2max of elite male kickboxers found in the literature range from 54 to 69 mL/kg/min [8,9].

Combat sports characterized by great intensity of actions are mostly based on anaerobic sources because decisive technical actions depend on quick and strong moves [10]. The energetic system adenosine triphosphate (ATP) and phosphocreatine (PCr) is very important for kickboxers because a proper strong blow can cause termination of a fight ahead of time (knock-out) [4,6]. A basic energetic source for this type of action includes anaerobic glycolysis; aerobic sources are important at the end of a fight (optimal aerobic and anaerobic endurance is necessary). A competitor's training should then include anaerobic power (dynamic kicks and punches) and strength and speed of upper limbs (blows and their combinations in attacks, blocks and ducks in defense) [11].

The strength of the muscles of upper and lower limbs plays an important role in winning in a kickboxing fight [12]. The results of isometric strength (e.g., the grip strength) are greatly accepted as indicators of the level of a kickboxer's strength [13,14]. The training process of kickboxers is diversified both in the context of the intensity of the training and the necessity of developing a wide range of motor skills [8,15]. Sports training in kickboxing is a subject of interest of many researchers [5,16,17]. A kickboxing fight is acyclic and its conditions change often (coordination and agility conditions). It has a holistic impact on the trainees and uses the whole organism, getting all groups of muscles active. The constantly changing situation in a bout requires good coordination and an immediate response to rival's actions. A bout duration is usually 3×2 min. and it characterizes many changes in effort intensity [11]. Physical effort is based on submaximal and maximal loads. The physiological profiles of competitors show that the physical training in kickboxing should be aimed at increasing both aerobic and anaerobic capacity. Due to training and starting loads (often at the level >90% VO_2max), muscle glycogen becomes the main source of energy. After terminating effort due to fatigue, glycogene is almost entirely used [18]. Using muscle glycogene in a given muscle group depends on the dynamics of movement in the ring, the frequency of changes in the intensity of the effort, methods of throwing kicks and punches and defensive reactions based mostly on anaerobic changes. Restoring glycogene takes place in after-effort restitution and its rate depends on many factors since there are moments of working on lower levels of VO_2max in competitions.

The optimal level of physical fitness of a competitor is the key element of efficiency in a sports competition. Thanks to defining the level of physical fitness, one can select training loads in the appropriate amounts of exercises with respect to both quality and quantity. Regular measurements of this level also allow the assessment of the effects of the training [19]. The strength and dynamics of upper limbs in kickboxing have been evaluated by measuring the distance in throwing a medicine ball [20,21], and the strength and the dynamics of lower limbs were evaluated by measuring the distance of a jump [8,22]. Kickboxers were observed to have high levels of strength, power, aerobic and anaerobic capacity combined with technical and tactical skills. This is the reason why physical training should be based on improving strength and capacity of the muscles in the limbs [23].

Due to detailed technical and tactical analyses it is possible to define competitors' training indicators as well as prove the existence of a relationship between the level of training and physical fitness of the participants. Technical and tactical analyses are common methods used in modifying the process of sport training in a group of martial arts and combat sports coaches and competitors. Interesting articles on this topic can be found in judo [24–26].

The results of the analysis of selected literature show that studies are concerned with success prognosis based on morpho-functional, physiological, biomechanical and psychosomatic indices [24], as well as assessment of capacity during fights [25,26]. Other studies were concerned with movement analysis [8], traumas and starting consequences [5,16]. A considerable deficit of texts regarding the level of training and the physical fitness of competitors was noted. The main objective of this paper is the assessment of the level of physical fitness of kickboxers in the highest sport level as well as finding a relationship between the fitness level and the indicators of technical and tactical training. Finding this correlation will determine whether the level of fitness influences activeness, effectiveness and efficiency of attacks and whether it allows more effective planning of sport training.

2. Materials and Methods

This study included 20 kickboxers presenting the highest level of sport. The selection of the group was intentional, and the criteria included training experience and the sports level assessed by observation of the authors and opinion of the coach. The participants were from 18 to 32 years old, their body mass ranged 75 to 92 kg and their height was between 175 and 187 cm. BMI of the participants ranged 24.13 to 28.73 kg/m^2(Table 1).

Table 1. Anthropometric characteristic of the participants.

Variables	No	Mean	95% Confidence Interval		Median	Minimum	Maximum	1st Quartile	3rd Quartile	Standard Deviation
Body mass	20	84.90	82.59	87.21	85.50	75.00	92.00	83.00	88.50	4.93
Height	20	181.05	179.46	182.64	180.00	175.00	187.00	179.00	183.50	3.39
BMI	20	26.04	25.46	26.62	25.99	24.13	28.73	25.15	26.73	1.24

BMI-Body Mass Index.

2.1. Physical Fitness Tests

The physical fitness of the participants was assessed by selected tests taken from the tests developed by the International Committee on the Standardization of Physical Fitness Tests (ICSPFT) and European Fitness Test (EUROFIT) [27]. The entire test included the following:

1. Aerobic capacity test—VO_2max (description of the test below)
2. Tapping—Assessment of speed of upper hands. The subject stands in front of a table with their feet spread and puts their worst hand on a rectangular pad. Their better hand is placed on a farther disc. They should touch both discs alternatively as quick as possible. The subject makes a total of 50 moves, they touch each disc 25 times. They take two tests and the best one is noted; the time is rounded to a decimal place.
3. Standing long jump—Jumping with both feet from standing. The test measures the distance jumped in cm, which is an indicator of the possibility to quickly create strength. The subject stands with their feet lightly spread behind the start line, they bends their knees moving their arms backward, then they move their arms forward, bounce their feet from the ground and make a jump as long as possible. They land on both feet in a standing position. The test is taken twice. The longer jump is recorded, rounded to the nearest cm.
4. Grip strength using a dynamometer. Evaluating the isometric strength. The subject has their feet lightly spread, the dynamometer lies close to fingers, arm down along the body but without touching the body. Short grip on a dynamometer using maximum strength, second arm loose along the body. Best of two tests is recorded; the result is rounded to 1 kg.
5. Shuttle run (10 $\times$ 5 m). The subject runs on a signal to the second line 5 m away, crosses it with both feet and comes back. They run 10 times for a distance of 5 m, the time of the shuttle run is measured and rounded to a decimal place of a second.
6. Pull-ups—Evaluating shoulder girdle strength counting the number of repetitions. The subject catches a bar, their hands are spread in line with their shoulders and they do an overhang. On a signal they bend their arms and pull up their body so their beard should be above the bar. After a moment of rest they return to an overhang. They repeat the exercise as many times as possible. The result is the number of repetitions.
7. Sit-ups—Evaluating abdominal muscle strength. The subject lies on a mattress, their feet are 30 cm apart and their knees bent at 90 degrees, with hands on their neck. A partner holds the subject's feet so they stay on the ground. On a signal the subject performs sit-ups touching their knees with their elbows and coming back to lying down. The test lasts 30 s.
8. Flexibility test—The subject bends their torso forward when sitting down and the range of motion behind feet is measured in cm. The sitting subject moves a ruler with their hands on a box with a scale. The best of two tests is recorded.
9. Cooper's test—Running endurance—12-min run, distance is measured.

The tests were done by the authors, with tests 1–4 on the first day, and tests 5–9 on the second. The volume of training was reduced to 30–40% two days before the tests.

2.2. Measuring the Indicators of Technical and Tactical Training

The analysis of a sports bout was done based on digital recording of a fight. Then, the indicators of technical and tactical training were computed using the following formulas [5].

Efficiency of the attack (S_a)

$$Sa = \frac{n}{N}$$

n—Number of attacks awarded 1 pt.*
* In K1 formula each fair hit is awarded 1 pt.
N—Number of bouts.
Effectiveness of the attack (E_a)

$$Ea = \frac{number\ of\ efective\ attacks}{number\ of\ all\ attacks} \times 100$$

* An effective attack is a technical action awarded a point.
* Number of all attacks is the number of all offensive actions.
Activeness of the attack (A_a)

$$Aa = \frac{number\ of\ all\ registered\ offensive\ actions\ of\ a\ kickboxer}{number\ of\ bouts\ fought\ by\ a\ kickboxer}$$

2.3. VO_2max Measurement

The test of maximal oxygen intake (VO_2max) was done with the use of the Margaria test. The participants climbed a step 40 cm tall. In the first 6-minute period the frequency of climbing was 15/min, in the second was 25/min. During both parts, heart rate was measured with sportster (Polar). The maximal oxygen intake was computed based on the formula in [28].

$$VO_2max = \frac{HRmax(VO2II - VO2I) + HRII * VO2I * VO2II}{HRII - HRI}$$

where:
HRmax—max heart rate [beats/min.]
*HRmax computed according to Tanaka 2001 (208 − 0.7*age) [29]
HRI—heart rate during I part [beats/min.]
HRII—heart rate during II part [beats/min.]
VO2I—estimated oxygen intake during I part [mL/O /kg/min],
that requires ca. 22.0 [mL/O /kg/min]
VO2II—estimated oxygen intake during II part [mL/O /kg/min],
that requires ca. 23.4 [mL/O /kg/min]

2.4. Bioethical Committee

Prior to participation in the tests, the competitors were informed about the research procedures, which were in accordance with the ethical principles of the Declaration of Helsinki WMADH (2000). Obtaining the competitors' written consent was the condition for their participation in the project. The research was approved by the Bioethics Committee at the Regional Medical Chamber (No. 287/KBL/OIL/2020).

2.5. Statistical Analysis

Statistical analysis of the data was done with the use of Statistica 13.1 by StatSoft. Parametric tests were used due to meeting the basic assumptions concerning the consistency of studied distributions to a normal distribution and the homogeneity of the variance. The consistency of the distributions to a normal distribution was evaluated with the use of a Shapiro–Wilk test, and the homogeneity of variance was evaluated with the use of a Levene test. All descriptive statistics (mean, median, minimum, maximum, 95% confidence intervals, 1st and 3rd quartile and standard deviation) were computed for all variables. The correlation of two variables of a normal distribution was evaluated with the use of a Pearson's linear correlation coefficient. The level of statistical significance was set to $p < 0.05$.

3. Results

The results of the fitness tests of the participants are shown in Table 2.

Table 2. The rezults of fitness test.

Variables	Number	Mean	95% Confidence Interval		Median	Minimum	Maximum	1st Quartile	3rd Quartile	Standard Dev.
Plate tapping [s]	20	7.64	7.17	8.10	7.25	6.46	9.43	6.89	8.18	1.00
Standing long jump [cm]	20	205.25	198.14	212.36	210.00	167.00	225.00	198.00	216.50	15.19
Cooper's test [m]	20	3086.20	2928.53	3243.87	3003.50	2656.00	3920.00	2837.00	3327.50	336.88
Static strength of a right hand [kg]	20	55.96	55.06	56.85	56.16	51.22	58.65	55.06	57.13	1.91
Static strength of a left hand [kg]	20	54.70	53.67	55.73	55.12	50.26	58.30	53.22	56.44	2.20
Pull-ups on a bar [n]	20	18.05	16.21	19.89	17.00	10.00	26.00	15.50	21.50	3.94
Shuttle run [s]	20	11.02	10.62	11.42	10.93	10.01	13.45	10.36	11.38	0.85
Flexibility [cm]	20	15.98	15.67	16.29	15.90	15.00	18.00	15.65	16.30	0.65
Sit-ups [n]	20	30.35	28.03	32.67	31.50	23.00	39.00	25.50	34.50	4.97

The mean level of aerobic capacity was 47.65 mL/kg/min and the results ranged from 41 to 56 (Table 3).

Table 3. VO2max.

Variables	Number	Mean	95% Confidence Interval		Median	Minimum	Maximum	1st Quartile	3rd Quartile	Standard Dev.
VO_2max [mL/kg/min]	20	47.65	45.59	49.71	49.00	41.00	56.00	43.00	51.00	4.39

Activeness of the attack was 96.8 on average and it ranged from 64 to 133. Effectiveness of the attack was 47.85 on average and it ranged from 40.6 to 56.32. Efficiency of the attack was 50.45 on average and it ranged from 45 to 56 (Tables 3 and 4).

Table 4. Activeness, effectiveness and efficiency of attacks.

Variables	Number	Mean	95% Confidence Interval		Median	Minimum	Maximum	1st Quartile	3rd Quartile	Standard Dev.
Activeness	20	96.80	89.46	104.14	92.00	64.00	133.00	89.00	102.50	15.69
Effectiveness	20	47.84	45.00	50.69	45.29	40.60	56.32	42.44	53.79	6.08
Efficiency	20	50.45	48.83	52.07	50.50	45.00	56.00	48.00	53.00	3.47

A strong negative correlation between aerobic capacity and the speed of upper limb and between aerobic capacity and shuttle run was shown as well as a strong positive correlation between aerobic capacity and standing long jump and between aerobic capacity and endurance. There was also a strong correlation between VO_2max and static strength of both hands and between VO_2max and abdominal muscle strength. It was also proven that body mass was strongly positively correlated with the speed of upper limbs and shuttle run as well as being negatively correlated with standing long jump and endurance. Participants who were quicker and more agile also had higher levels of the indicators of activeness, effectiveness and efficiency of attacks (strong negative correlation of the indicators with speed and shuttle run and strong positive correlation with standing long jump and endurance). Participants who had higher results of standing long jump or Cooper's test also had higher levels of the indicators. The efficiency of attacks was correlated with abdominal muscle strength (Table 5).

Table 5. The influence of selected variables on the results of fitness tests.

Pearson's Linear Correlation Coefficient r Level of Significance *p*	VO_2max	Body Mass	Height	BMI	Activeness	Effectiveness	Efficiency
Plate tapping [s]	−0.89 0.001	0.80 0.001	0.52 0.020	0.55 0.013	−0.55 0.013	−0.79 0.001	−0.82 0.001
Standing long jump [cm]	0.85 0.001	−0.72 0.001	−0.57 0.009	−0.40 0.077	0.52 0.019	0.74 0.001	0.85 0.001
Cooper's test [m]	0.87 0.001	−0.87 0.001	−0.59 0.007	−0.50 0.026	0.80 0.001	0.67 0.001	0.70 0.001
Static strength of a right hand [kg]	0.74 0.001	−0.60 0.005	−0.61 0.004	−0.22 0.350	0.50 0.026	0.51 0.021	0.77 0.001
Static strength of a left hand [kg]	0.67 0.001	−0.55 0.012	−0.42 0.065	−0.54 0.015	0.34 0.143	0.65 0.002	0.73 0.001
Pull-ups on a bar [n]	−0.22 0.349	0.28 0.238	0.44 0.052	−0.07 0.766	−0.19 0.430	−0.19 0.415	−0.22 0.349
Shuttle run [s]	−0.85 0.001	0.82 0.001	0.71 0.001	0.33 0.155	−0.63 0.003	−0.70 0.001	−0.85 0.001
Flexibility [cm]	−0.14 0.550	−0.01 0.970	0.14 0.561	−0.03 0.903	−0.06 0.805	−0.06 0.817	−0.10 0.666
Sit-ups [n]	0.52 0.019	−0.26 0.263	−0.28 0.234	−0.13 0.587	0.13 0.587	0.42 0.068	0.49 0.027

Participants who had higher levels of VO_2max also had higher levels of indicators of activeness, effectiveness and efficiency of attacks. All correlations were strong and statistically significant. Moreover, lighter and shorter participants also had higher levels of the indicators. Correlations between body mass and the levels of indicators of activeness, effectiveness and efficiency of attacks were strong and the correlations between the height and the levels of indicators of activeness, effectiveness and efficiency of attacks were medium; all correlations were significant. Effectiveness of the attack was significantly negatively correlated to the BMI of the participants. The correlation had a medium strength (Table 6).

Table 6. The influence of selected variables on the activeness, the effectiveness and the efficiency of attacks.

Pearson's Linear Correlation Coefficient (r) Level of Significance *p*	VO_2max	Body Mass	Height	BMI
Activeness	0.72 0.001	−0.82 0.001	−0.58 0.007	−0.35 0.131
Effectiveness	0.70 0.001	−0.74 0.001	−0.58 0.007	−0.51 0.021
Efficiency	0.88 0.001	−0.71 0.001	−0.69 0.001	−0.32 0.175

4. Discussion

A kickboxing bout in a K1 rules competition is dynamic as well as comprehensive in the technical and tactical aspects [4]. Contenders who fight in the highest level competitions must have proper aerobic capacity. In this study, the mean result of the participants' level of VO_2max was 47.65 mL/kg/min, which can be interpreted as a high level of aerobic capacity [16,17]. In other combat sports the mean level of competitors' VO_2max was as follows: 40.8 mL/kg/min (judokas), 50.3 mL/kg/min (boxers), 58.4 mL/kg/min (MMA fighters) [30–32]. The participants of this study had better VO_2max level than judokas, but were worse than MMA fighters and comparable to boxers. Statistical analysis showed a strong and significant correlation between the level of VO_2max and the activeness, the effectiveness and the efficiency of the participants. This can show that the level of indicators of technical and tactical training depends on aerobic capacity and they can be related to general endurance of the organism (VO_2max underlies the endurance) that is considered as the basis of physical possibilities of a competitor [33]. Statistical analysis also showed significant negative correlations between the speed of upper limbs and the indicators of technical and tactical training. The correlations were strong (with the efficiency of the attack) and medium (with other indices). Similarly, there were strong (with the efficiency) and medium (with other indices) correlations between shuttle run and the indicators. Thus it follows that the competitors whose results in speed and agility test were worse, were more active and had greater effectiveness and efficiency of their attacks than the participants with better results in those tests. The higher the speed of the upper limbs, the higher the number of competitor's actions involving hand techniques in a round. Good upper limb speed also corresponds to better defensive actions. Due to great similarity in the actions involving upper limbs in both boxers and kickboxers, the analysis of the results of this study could be also done in the study of boxers and the results would be similar [34,35]. Competitors who had quicker upper limbs were able to use more techniques which resulted in increasing their activeness, effectiveness and efficiency indicators. Similar results were reached in assessing agility (as speed and coordination) which is characteristic and significant in kickboxing competitions. Thanks to a high level of agility it is possible to move more smoothly in a ring, which makes attacks more effective (one can surprise a rival with feints, change of pace and anticipating the attack) and improves defensive actions (dodging, ducks, turns). Speed and coordination are basic elements of a kickboxing fight and they underlie proper timing, which means using a technique in the right moment [8,15,23].

There were strong positive correlations between the results of most of the fitness tests and the levels of the indicators of technical and tactical training. It was shown that a high level of maximum anaerobic power was assessed with the use of the standing long jump test. It is worth noticing that Ambroży et al. proved that a high round kick was the most effective lower limb technique, and could often end a fight with a knock-out [4]. Dynamic strength determines the efficiency of doing kicks and it could also improve the indicators of technical and tactical training [36]. Static strength is an important element of the motor preparation of a competitor. Its high level gives the possibility of increasing the technical potential of a kickboxer [37]. In this study we showed the existence of medium strength significant correlations between the technical and tactical training indicators and the static strength of a hand. The analysis of the results shows that there is a medium strength relationship between the abdominal muscle strength and the effectiveness of a competitor in a kickboxing fight. The training process in kickboxing is based on comprehensive development of abdominal muscles, which guarantees an effective defense, protecting a fighter's torso. This is the reason why this relationship can be a direct effect of the training methods used.

This study showed a negative correlation between body mass and height vs. the level of indicators of technical and tactical training. The strength of the correlations was usually medium, and only in the case of the relationship between body mass and activeness of the attack was the correlation strong. Participants competing in lower weight categories can punch and kick faster but at the cost of the strength of a blow [38]. That could be a reason why lighter and shorter participants had better results of activeness, but also effectiveness and efficiency of attacks in comparison to heavier and taller kickboxers. Tests conducted in this study did not prove the existence of significant relationships between shoulder girdle strength (pull-ups) and the level of the indicators of technical and tactical training. Thus it follows that shoulder girdle strength is not a significant element of a kickboxing competition according to K1 rules. Similarly, there was no significant relationship between the level of agility and the level of the indicators of technical and tactical training. Competitors fighting according to K1 rules use mostly low kicks on the thigh or high round kicks that do not require an above average developed agility level.

This way of fighting could point, for example, to the lack of agility predispositions in some competitors, which, as can be seen, is not an element that could decide the win in a kickboxing fight.

5. Conclusions

Activeness, effectiveness and efficiency of the competitors expressed by the indicators of technical and tactical training show a strong correlation to the level of maximum oxygen intake VO_2max. It follows that kickboxers should work out the optimal level of aerobic capacity in a preparation term and then maintain this during the competitions. It should impact their starting possibilities.

The level of the speed of upper limbs and agility influence the starting possibilities measured with the use of the indicators of technical and tactical preparations. This is closely connected to efficiency of a kickboxing fight.

Efficiency, effectiveness and activeness of an attack depend on the level of muscle strength of upper, middle and lower parts of the body.

Somatic features of the competitors influence activeness, effectiveness and efficiency of attacks. The relationships show the necessity of controlling body mass before the start of a competition and keeping it at the optimum level in the aspect of weight categories.

Practical Implication

The training process of kickboxers fighting according to K1 rules should be based on the comprehensive development of a competitor in the aspects of strength, speed and endurance, while keeping the optimal body weight should underlie the training process.

Author Contributions: Conceptualization, Ł.R.; methodology, Ł.R.; validation, Ł.R.; formal analysis, Ł.R., T.A.; resources, Ł.R.; data curation, Ł.R.; writing—original draft preparation, Ł.R., T.A.; writing—review and editing, Ł.R., T.A.; supervision, T.A.; project administration, Ł.R.; funding acquisition, T.A. All authors have read and agreed to the published version of the manuscript. Please turn to the CRediT taxonomy for the term explanation. Authorship must be limited to those who have contributed substantially to the work reported.

Funding: This research received no external funding.

Institutional Review Board Statement: The research was approved by the Bioethics Committee at the Regional Medical Chamber (No. 287/KBL/OIL/2020)

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

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Załącznik nr 4

Rydzik, Ł.; Maciejczyk, M.; Czarny, W.; Kędra, A.; Ambroży, T. Physiological Responses and Bout Analysis in Elite Kickboxers During International K1 Competitions. *Front. Physiol.* **2021**, *12*, 737–741, doi:10.3389/fphys.2021.691028.

https://www.frontiersin.org/articles/10.3389/fphys.2021.691028/full (dostęp 27.01.2023 r.)

ORIGINAL RESEARCH
published: 16 July 2021
doi: 10.3389/fphys.2021.691028

Physiological Responses and Bout Analysis in Elite Kickboxers During International K1 Competitions

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Background: Kickboxing is a combat sport with various forms of competition. Kickboxing according to the K1 rules is one of the most interesting and quickly developing forms of kickboxing. According to the K1 rules, it is possible to use a variety of techniques with great force. The aim of this study was to investigate the physiological responses during a real sports fight and to perform a technical and tactical analysis of the kickboxing bout according to the K1 rules.

Methods: This study was conducted during two cycles of the international kickboxing league according to the K1 rules in a group of 15 elite athletes. The indicators of technical and tactical training were evaluated in real sports bout. Blood lactate (LA) levels and heart rate (HR) were measured during and after the bout.

Results: The efficiency of the attack was on average 59.3 ± 2.7, its effectiveness was 50.3 ± 10.01, and its activeness was 112.3 ± 29. The peak LA concentration was 14.6 ± 1.9 mmol/L. LA concentration did not decrease to baseline after 20 min of recovery.

Conclusion: A kickboxing bout was found to induce strong physiological stress for the participants. Reported HR and LA concentration show that the intensity of the fight was close to maximal, and anaerobic metabolism played an important role during a fight.

Keywords: sports, kickboxing, fight analysis, heart rate, lactate

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Specialty section:
This article was submitted to Exercise Physiology, a section of the journal Frontiers in Physiology

Received: *05 April 2021*
Accepted: *10 June 2021*
Published: *16 July 2021*

Citation:
Rydzik Ł, Maciejczyk M, Czarny W, Kędra A and Ambroży T (2021) Physiological Responses and Bout Analysis in Elite Kickboxers During International K1 Competitions. Front. Physiol. 12:691028. doi: 10.3389/fphys.2021.691028

INTRODUCTION

Kickboxing is a striking combat sport that is very dynamic and characterized by high intensity (Di Marino, 2018). It requires a variety of complex skills and tactical excellence. Kickboxers are classified by gender, body mass, and age (Kordi et al., 2009). Kickboxing is characterized by continuous changes in movement structure under undetermined conditions, with variable work intensity and load duration (Krupalija et al., 2010). Most studies of kickboxers have been based on full-contact competitions, where, according to the rules, low kicks and knee strikes are not allowed. Previous studies have dealt with the physique of athletes, physiological responses, and time-motion and technical-tactical analyses in kickboxing athletes during simulated fights and training (Ouergui et al., 2013a, 2014b, 2016, 2019).

It is worth noticing that a kickboxing bout engages all muscle groups, requires coordination, and activates both aerobic and anaerobic metabolism (Senduran and Mutlu, 2017). A sports fight in K1 kickboxing is characterized by acyclic exercise and frequent changes of fighting conditions, which require good coordination and agility. This affects the athletes holistically and comprehensively engages the entire body by activating all muscle groups. With constant changes of a situation during a bout, the athletes need to show a keen level of proprioception, fast reaction time (both simple and complex), good hand-eye coordination (Akman et al., 2018), and spatial orientation and react immediately to the actions of his or her opponent (Slimani et al., 2017b). Preferred efforts both during the bout and training are based on submaximal and maximal loads (Rydzik and Ambrozy, 2021). However, there are no data concerning physiological responses to an effort during a real sports fight.

The efficiency of kickboxing techniques is based on a keen sense of the possibility of striking once or more than once. The strike requires high anaerobic power, while exercise during all intervals between strikes is based on aerobic metabolism (Ambrozy et al., 2020). Deciding moments of a fight that precede its settling (i.e., supramaximal intensity efforts requiring high power, speed, or strength from the athlete) are based on the alactic anaerobic energy pathway, but a high level of aerobic capacity is required for quick recovery between dynamic anaerobic efforts. This was confirmed by Zabukovec and Tiidus, who showed that elite kickboxers demonstrate a high level of aerobic and anaerobic fitness along with the ability to produce high muscle power (Zabukovec and Tiidus, 1995). Also, Ouergui et al. claim that kickboxing training should be aimed at improving the anaerobic capacity of athletes (Ouergui et al., 2014a). Although some studies on kickboxing have addressed these problems (Slimani et al., 2017b), few studies have explored physiological characteristics and performance aspects in kickboxers concerning weight categories in different kickboxing styles. However, each striking combat sport has its own rules, weight divisions, competitive levels, specific techniques, and consequently, different variables contributing to the success (Slimani et al., 2017c). The K1 formula is an interesting and dynamically developing kickboxing style. In the K1 rules, it is allowed to use many more techniques and strikes with a great force (Rydzik et al., 2020). All punches and kicks are allowed without restrictions on a striking force. During a fight, competitors can use all of the following techniques: roundhouse kick, front kick, side kick, axe kick, knee kick, back fist, and all boxing techniques. Competitors in the amateur type of K1 are characterized by a high sports skill level. Most of the skills defined as fighting techniques are determined by the optimal level of general and special physical fitness. For example, hand strikes, which are the basic technical elements in K1, require a high level of speed, dynamic strength of the upper limbs, and coordination of the whole body. Kicks primarily require good joint mobility (flexibility) and dynamic strength of the lower limbs (Rydzik and Ambrozy, 2021). Learning technical skills is the basis for tactical actions during the fight. Tactical actions are skills that athletes acquire through training and competitive experience. Tactics refers to offensive actions (i.e., combinations, agility, and timing) and defensive actions (i.e., dodges, blocks, and counterattacks). Tactical actions cannot be performed without proper technique and constitute a specific type of skill that guarantees success during the competition (Poteryakhin et al., 2021). According to the World Association of Kickboxing Organizations (WAKO), a kickboxing bout should consist of three 2-min rounds with 1-min breaks.

A detailed analysis of the physiological responses of the fighter during a fight is a key training parameter (Ouergui et al., 2013b). Studies concerning physiological responses during a real sports fight are especially valuable because they allow for the assessment of the workload during a fight and making adjustments in training to better fit the requirements of the fight (Slimani et al., 2017b). In addition to studying the physiological responses during kickboxing bouts, the hormonal responses of the body have also been examined (Moreira et al., 2010). Slimani et al. (2017a) studied kickboxers during a bout by dividing the time structure into three phases (i.e., preparatory activity time, fighting time, and break time). Based on the determination of the effectiveness of the fight and the combination of techniques used in individual phases, it was proposed to adapt the training programs to the specific requirements of weight categories and gender of kickboxers in order to develop technical–tactical skills that increase the chances of victory (Slimani et al., 2017a).

Additionally, a detailed technical analysis of a sports fight provides important information concerning further training. Computing the indicators of technical and tactical preparation is the best method of the assessment of the level of the training in this aspect (Adam and Sterkowicz-Przybycień, 2018). It allows for training optimization and implementation of specific training methods and techniques aimed at maximizing the exercise capacity of athletes (Moreira et al., 2010). Studies that assessed the physiological responses during a real sports fight are rare but they provide much valuable information. To our knowledge, this is the first study to analyze the fight in the aspect of physiological stress during a real rather than simulated sports fight during a competition. The main aim of this study was to evaluate physiological responses to a real sports fight according to the K1 rules. An additional aim was to make a technical and tactical analysis of the bout according to the K1 rules, which will allow for the evaluation of the ability of athletes to succeed in a real fight.

MATERIALS AND METHODS

Study Design

This study was conducted during two cycles of the international kickboxing league according to the K1 rules in a group of 15 elite kickboxers. The inclusion criterion was the sports skill level determined based on the balance of fights won by the athlete. The measurements were done during a fight (consisting of three 2-min rounds) and following the fight. This study covered the technical analysis of the bout and measurements of lactate (LA) concentration and heart rate (HR). The following physiological measurements were taken: after the warm-up, when the athlete was ready to fight, directly after each round, and during recovery after the bout (**Figure 1**).

TABLE 1 | Characteristics of the study group.

Characteristics	$\bar{x}$	−95%CI	+95%CI	SD	Min	Max	Q1	Q3
Age [ys]	23.9	21.4	26.5	4.6	19.0	34.0	20.0	26.0
Height[cm]	177.1	174.4	179.7	4.8	168.0	185.0	174.0	181.0
Body mass [kg]	79.1	75.9	82.2	5.6	67.0	86.0	75.0	84.0
BMI [kg/m^2]	25.2	24.5	25.9	1.3	21.4	27.1	24.8	25.7
Training experience [ys]	9.9	6.9	12.8	5.3	4.0	25.0	6.0	11.0

TABLE 2 | Lactate concentration in subsequent measurements.

La [mmol/L]	$\bar{x}$	−95%CI	+95%CI	SD	Min	Max	Q1	Q3	p_1	p_2	ES1	ES2
Baseline	2.2	1.7	2.7	0.9	1.5	5.1	1.6	2.6	–	–	–	–
After 1 round	11.3	10.5	12.1	1.4	8.5	13.9	10.2	12.2	**<0.001**	**<0.001**	6.50	10.11
After 2 round	13.1	12.4	13.7	1.2	11.3	14.8	12.0	14.1	**<0.001**	**0.007**	9.08	1.29
After 3 round	14.6	13.6	15.7	1.9	10.0	16.9	13.4	16.2	**<0.001**	**0.024**	6.53	1.25
3 mins after fight	11.2	0.9	2.0	1.3	8.6	13.2	10.1	12.3	**<0.001**	**<0.001**	6.92	1.79
20 mins after fight	5.1	0.9	2.0	1.3	3.2	7.6	3.6	6.0	**<0.001**	**<0.001**	2.23	4.69
p (ANOVA)	<0.001											

Statistically significant values are in bold.

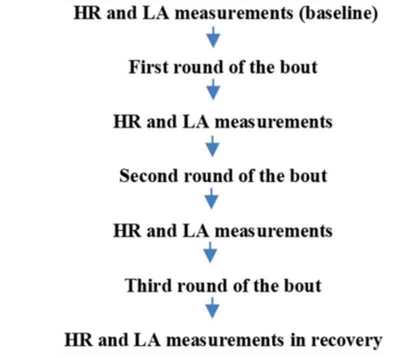

FIGURE 1 | Study design.

The fights were video recorded, and each recording was analyzed by an experienced coach for studied indicators (i.e., activeness, effectiveness, and efficiency of the attack). All participants provided their written consent to participate in the project. This study was approved by the Bioethical Committee at the Regional Medical Chamber in Kraków (No. 287/KBL/OIL/2020).

Characteristics of the Participants

The mean age of the participants was 23.9 ± 4.6 years. The participants had practiced kickboxing for 9.9 ± 5.3 years on average (**Table 1**). Kickboxers were trained 5–6 times a week and were elite athletes who fought on average 20 kickboxing bouts a year. The somatic characteristics of the participants are presented in **Table 1**.

Analysis of the Fight

The analysis of the sports fight was performed by two champion-level kickboxing coaches and one referee based on digital video recordings of the examined athlete. The recording was made with three cameras. Movavi Video Editor 14 software (Movavi, Wildwood, MO, USA) was used to merge the images. The setting of cameras allowed continuous observation of the athletes, referees, and the scoreboard. A single sheet was developed as the essential research tool. Each expert had a separate measurement sheet on which they recorded the techniques used and those completed successfully. The data from all the measurement sheets were entered in an Excel sheet, where the means of the ratings of the three experts were computed for each athlete. Then the values of technical and tactical preparation indices were calculated. In the evaluation of the efficiency of the attack during K1 competitions, each fair hit gets 1 point. In the effectiveness of the attack, the effective attack is a technical action awarded a point, and an attack is defined as an offensive technical action. The indicators of technical and tactical training were computed using the following formulae (Rydzik et al., 2020; Rydzik and Ambrozy, 2021).

Efficiency of the attack (S_a)

$$S_a = \frac{n}{N}$$

where n is the number of attacks awarded 1 pt.* and N is the number of fights observed (it is 1 in this study).

Effectiveness of the attack (E_a)

$$E_a = \frac{number\ of\ efective\ attacks}{number\ of\ all\ attacks} \times 100$$

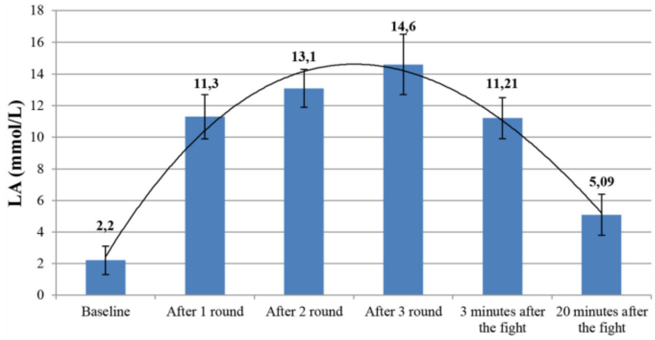

FIGURE 2 | Lactate concentration in subsequent measurements.

TABLE 3 | Heart rate in subsequent measurements.

HR	$\bar{x}$	−95%CI	+95%CI	SD	Min	Max	Q1	Q3	p_1	p_2	ES1	ES2
Baseline	97.5	94.3	100.6	5.6	89.0	107.0	93.0	102.0	–	–	–	–
After 1 round	178.2	175.1	181.3	5.5	172.0	190.0	174.0	183.0	**<0.001**	**<0.001**	14.67	14.41
After 2 round	182.1	180.0	184.3	3.8	176.0	191.0	180.0	184.0	**<0.001**	0.989	22.26	0.71
After 3 round	185.0	183.1	186.9	3.4	180.0	192.0	183.0	188.0	**<0.001**	0.999	25.74	0.76
2 min after fight	133.2	125.8	140.6	13.3	117.0	162.0	120.0	138.0	**<0.001**	**<0.001**	2.68	15.24
3 min after fight	122.6	115.0	130.2	13.7	105.0	163.0	116.0	128.0	**<0.001**	0.084	1.83	0.80
4 min after fight	114.1	105.4	122.9	15.8	93.0	165.0	107.0	117.0	**<0.001**	0.348	1.05	0.62
5 min after fight	107.6	102.9	112.3	8.1	96.0	120.0	102.0	115.0	0.140	0.750	1.25	0.41
6 min after fight	106.9	101.3	112.5	8.3	96.0	122.0	99.0	114.0	0.309	1.000	1.13	0.09
7 min after fight	104.0	98.2	109.8	7.5	90.0	112.0	102.0	109.0	0.873	1.000	0.87	0.35
8 min after fight	100.2	93.3	107.1	9.0	88.0	111.0	90.0	106.0	1.000	0.999	0.30	0.51

$\bar{x}$, mean; Min, minimum; Max, maximum; Q1, 1st quartile; Q3, 3rd quartile; SD, standard deviation.
p_1–post-hoc: difference to baseline Tukey's test.
p_2–post-hoc: difference between two consecutive measurements, Tukey's test.
ES1—effect size to baseline.
ES2—effect size between two consecutive measurements.
Statistically significant values are in bold.

Activeness of the attack (A_a)

$$A_a = \frac{\textit{number of all registered offensive actions of a kickboxer}}{\textit{number of fights fought by a kickboxer (1 in this study)}}$$

Physiological Measurements

Heart rate measurement was performed using an HR monitor by Garmin Fenix 6 (Olathe, USA) with a chest strap. The first measurement was taken after a warm-up when a competitor was ready to fight. Subsequent measurements were taken directly after the first, second, and third rounds, and the final measurement was taken after the fight until the rest HR was equal to that when the athlete was ready to fight. The athletes were wearing the strap during 1-min breaks between rounds, and then the HR value was recorded. The measurements were taken during 1-min breaks between the rounds. Based on the received values of HR, a recovery index (RI) was calculated (Zatoń and Jastrzebska, 2010).

$$RI = \frac{HR2 - HR3}{HR2 - HR1} \times 100\%$$

where HR1 is the baseline heart rate, HR2 is the peak heart rate noted immediately after the fight, and HR3 is the HR after 5 min of recovery.

Recovery index allows for the assessment of the efficiency of recovery. In the interpretation of RI, the following ranges were defined: <50%: poor recovery, 50–60%: average recovery, 60–80%: good recovery, and >80%: very good recovery.

The measurement of blood LA levels was performed with the use of Lactate Scout (Sweden) by taking a blood sample by finger stick. The first sample was obtained after the warm-up, and the subsequent samples were taken after each round of the fight

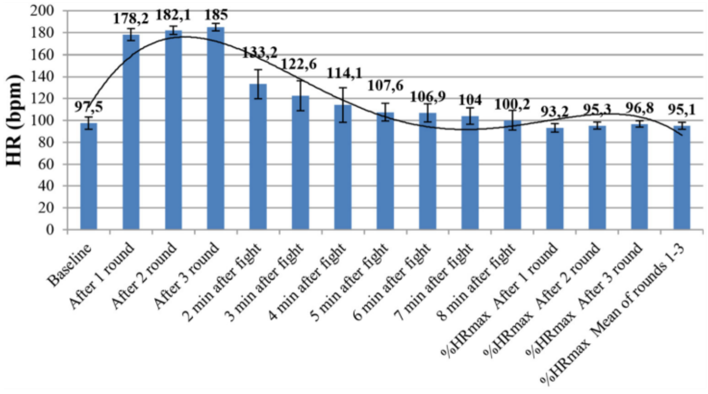

FIGURE 3 | Heart rate in subsequent measurements.

TABLE 4 | Activeness, effectiveness, and efficiency of the attack.

	n	$\bar{x}$	−95%CI	+95%CI	Min	Max	Q1	Q3	SD
Descriptive statistics									
Efficiency	15	59.3	57.8	60.7	55.2	65.2	57.1	61.2	2.7
Effectiveness	15	50.3	44.7	56.0	31.0	65.0	41.0	61.0	10.1
Activeness	15	112.3	96.2	128.4	53.0	160.0	101.0	129.0	29.0

during 1-min breaks between the rounds and after the fight in the 3rd and 20th minutes of recovery.

Statistical Methods

The statistical analysis was conducted using Statistica 13.1 by StatSoft (Krakow, Poland). The data were tested for normal distribution using the Shapiro–Wilk test. ANOVA with repeated measures was used to compare the mean value of a variable in one measurement with the previous measurement. The homogeneity of variance within the groups was tested with the Levene's test. The Tukey's *post-hoc* test was also used, and the effect size was calculated. In basic descriptive statistics, arithmetic mean, standard deviation, minimal and maximal values, 95% CI, and first and third quartiles were used. The level of statistical significance was set at $p < 0.05$.

RESULTS

The bouts induced strong physiological stress in the participants. A significant increase in the HR ($f = 4{,}502.30$ and $p < 0.001$) and blood LA ($f = 26{,}425.45$ and $p < 0.001$) were found during the fight. The peak LA concentration was noted in the third round (14.6 ± 1.9 mmol/L), and 20 min after the fight, it remained significantly higher compared with baseline (**Table 2** and **Figure 2**). During the fight, the HRs were constantly increasing round after round and reached peak levels in the last round (185 ± 4.4 bpm). After the bout, the HR decreased to baseline after 5 min of recovery (**Table 3** and **Figure 3**). The average RI in the fifth minute after the bout was 89.8% ± 10.4%. The average efficiency of the attack was 59.3 ± 2.7, its effectiveness was 50.3 ± 10.01, and activeness was 112.3 ± 29 (**Table 4**).

DISCUSSION

The objective of this study was to analyze the physiological responses during a real sports fight and to perform a technical and tactical analysis of the bout conducted according to the K1 rules. This study showed that a fight according to the K1 rules represented strong physiological stress for competitors. Blood LA levels after the bout exceeded 14 mmol/L. In this study, we used RI for the first time to analyze the physiological response. The recovery time, time, which should be as short as possible, can be an indirect indicator of aerobic capacity. A RI of ca. 90% indicates the high effectiveness of training used to develop aerobic capacity in kickboxers. Recovery time depends mostly on aerobic fitness and the ability to quickly recover, especially between the rounds. It is also essential for restoring the phosphagen level. Phosphagen, which is also restored through aerobic metabolism, is crucial for high-force kicks and punches. The data obtained in this study show that in order to meet the physiological demands in K1 formula, the competitors need comprehensive fitness training. To our knowledge, this study is the first to assess the physiological responses in this kickboxing style and can be compared only with different kickboxing formulae or different combat sports. A previous study (Ambrozy et al., 2020) showed that the performance of male kickboxers primarily depended on the alactic anaerobic and aerobic power, whereas our data also show that it is necessary for athletes to improve glycolytic anaerobic capacity, which was confirmed by a high LA concentration measured in the subsequent rounds of the bout. K1 formula is the most contact type of kickboxing and that can be a reason why the HR in this type of competition is usually higher than that in other kickboxing styles. Furthermore, the athletes often want to terminate the fight quickly in the first round and therefore they engage in the fight in the first round to a maximal level. In the K1 formula, athletes also perform the techniques at maximal intensity in order to terminate the fight quickly. Every technique performed by a kickboxer at maximal intensity causes an increased physiological response. In the study by Ghosh (2010), he presented the mean HR of boxers during a three-round bout (178 bpm). In contrast, during a 2-min contact karate bout, the HR was 160 bpm (Tabben et al., 2013). In this study, HR after 2 min of the fight was 18 bpm higher, which is likely to have resulted from a different character of the fight or a possibility of punching the head in K1 kickboxing, which is banned in kumite. A study of Turkish kickboxers showed the mean HR of 127 bpm, which is significantly lower than in fighters competing in K1 formula (Ambrozy et al., 2020). Both HR and exercise intensity were constantly rising in the subsequent rounds. It was observed that kickboxers experienced higher physiological stress and lower work outputs during consecutive rounds (Salci, 2015). Ouergui et al. (2019) observed a similar effect in their study. They recorded the highest increase in HR in the first round of the fight and the same increase in the third round. A similar round-to-round increase was observed in blood LA, which showed a gradual increase of glycolytic anaerobic potential during the bout. The mean LA concentration during the fight was close to that observed in Japanese semiprofessional K1 kickboxers (Ghosh, 2010) and higher than that observed in karate, taekwondo, and boxing (Ghosh, 2010; Tabben et al., 2013; Kim et al., 2014).

The achievement of the second aim of this study, which was to perform a technical and tactical analysis of the kickboxing bouts, is undoubtedly a novelty. Three parameters (i.e., the efficiency of the attack, the effectiveness of the attack, and the activeness of the attack) were used to assess the bouts. The level of activeness is measured by the number of techniques used (Ambrozy et al., 2021).

According to Laskowski et al. (2006), the far-reaching individualization of teaching technical and tactical skills should be an important element of the training process at the elite level. However, it seems appropriate to look for directions of changes within the sports fight depending on its physiological profile, which was the focus of this study.

Determination of the indicators of technical and tactical skills represents basic verification of the progress of athletes and helps compare him or her with other athletes. The indicators also allow for the identification of certain gaps in training. In this study, the level of the indicators of technical and tactical skills was at a high level compared with recent studies conducted by Ambrozy et al. (2021). All indicators were well above the average compared with the highest competitive disposition presented by the authors. This demonstrates that this study examined elite athletes, who at the time of measurement were characterized by an excellent competitive disposition. Previous study (Rydzik and Ambrozy, 2021) showed that elite kickboxers should be characterized by an ability to perform a wide range of tactical actions and optimally developed physical fitness. This level of preparation allows the athlete to quickly gain a point advantage, which may increase the likelihood of success (Boguszewski, 2014). The data show that in this kickboxing style (K1), the athletes require complex physical training to improve both aerobic and anaerobic capacities (Boguszewski, 2014).

Limitation of This Study

The analysis of physiological responses during a sports fight is difficult and limits the study methodology and tools that can be used in a study. In this study, the measurements were limited to HR and blood LA, which are the only measurements possible to conduct during competition. As the measurements were taken during the real bout, the referees did not agree to wear the chest strap during the bout for safety reasons of athletes. Therefore, HR was measured by means of a chest strap that was put on the body of athletes immediately after each round of the fight. Unfortunately, we could not measure HRmax accurately, e.g., during a graded exercise test due to taking measurements during the real fight and express fight intensity as %HRmax. We used the highest recorded HR immediately after the bout to calculate the RI of HR. During the bout, HR increased steadily in subsequent rounds, but it is possible that during the third round, the HR was higher than immediately after the bout. However, for procedural reasons, it is impossible to measure HR during the fight.

In contrast, these are basic measurements that can be used to monitor training progress. Sports skill level or the fighting style of opponents can also influence the technical and tactical indicators or the physiological responses. Therefore, further research is needed to explore, e.g., physiological responses during a simulated fight, where more variables can be controlled.

CONCLUSIONS

A fight was found to cause strong physiological stress for the fighters. Reported HR and LA concentration show that the intensity of work was close to maximal, and the anaerobic energy pathway was an important energy system contribution during a K1 fight. The data show that in this kickboxing style, athletes require comprehensive strength and conditioning programs to improve both aerobic and anaerobic capacities.

Application

Efforts of the intensity close to maximal or supramaximal (i.e., alactic and lactic) should dominate in the training that prepares the kickboxers to competition according to the K1 rules. Using this type of effort in the training corresponds to the physiological requirements of the actual fight and should lead to the optimal fitness of a kickboxer.

DATA AVAILABILITY STATEMENT

The data presented in this study are available on request from the corresponding author.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by The study was approved by the Bioethical Committee at the Regional Medical Chamber in Kraków (No. 287/KBL/OIL/2020). The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

Conceptualization, Formal analysis, Investigation, Data curation, Writing—original draft preparation, Visualization, and Project administration: ŁR. Methodology: ŁR and MM. Software: AK and ŁR. Validation: ŁR and WC. Resources and Writing—review and editing: ŁR, MM, and TA. Supervision: TA and WC. Funding acquisition: MM. All authors contributed to the article and approved the submitted version.

FUNDING

Open Access financed by the program of the Minister of Science and Higher Education entitled Regional Initiative for Perfection within the years 2019–2022, Project No. 022/RID/2018/19, in the total of 11919908 PLN.

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Conflict of Interest: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Załącznik nr 5

Rydzik, Ł.; Ambroży, T.; Obmiński, Z.; Błach, W.; Ouergui, I. Evaluation of the Body Composition and Selected Physiological Variables of the Skin Surface Depending on Technical and Tactical Skills of Kickboxing Athletes in K1 Style. *Int. J. Environ. Res. Public Health* **2021**, *18*, 11625, doi:10.3390/ijerph182111625.

https://www.mdpi.com/1660-4601/18/21/11625 (dostęp 27.01.2023 r.)

International Journal of
Environmental Research and Public Health

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Article

Evaluation of the Body Composition and Selected Physiological Variables of the Skin Surface Depending on Technical and Tactical Skills of Kickboxing Athletes in K1 Style

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Abstract: Background: Kickboxing is a combat sport with high demands on fitness and coordination skills. Scientific research shows that kickboxing fights induce substantial physiological stress. Therefore, it is important to determine the body composition of athletes before competitions and to analyze the skin temperature and skin pH during the fight. Methods: This study aimed to determine the body composition, skin temperature, and skin pH in kickboxers during a fight according to K1 rules. A total of 24 kickboxers (age range: 19 to 28 years) competing in a local K1 kickboxing league participated in the present study. Results: Changes in skin temperature and pH were observed and significant correlations were found between body composition and weight category. Conclusions: Changes in skin temperature and pH were demonstrated after each round of the bout. Level of body fat and muscle tissue significantly correlates with technical-tactical skills of the K1 athletes studied.

Keywords: skin temperature; skin pH; kickboxing contest; body composition

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Citation: Rydzik, Ł.; Ambroży, T.; Obmiński, Z.; Błach, W.; Ouergui, I. Evaluation of the Body Composition and Selected Physiological Variables of the Skin Surface Depending on Technical and Tactical Skills of Kickboxing Athletes in K1 Style. *Int. J. Environ. Res. Public Health* **2021**, *18*, 11625. https://doi.org/10.3390/ijerph182111625

Academic Editor: José Carmelo Adsuar Sala

Received: 26 September 2021
Accepted: 1 November 2021
Published: 5 November 2021

1. Introduction

Kickboxing is a physically demanding combat sport with a high focus on coordination skills, with many systems and organs of the human body involved during the fight [1]. To score points and defeat the opponent, kickboxers use both upper limbs, in an attempt to deliver punches, and lower limbs, used to perform kicks [2]. The K1 formula places the least restrictions on the techniques used and the strength of their execution. It allows for all kickboxing techniques to be performed without any restrictions on the strength of the blows. The competitors fight with naked torsos in shorts, wearing helmets on their heads, gloves on hands, and shin and feet guards. Fights, according to the regulations of the World Association of Kickboxing Federation (WAKO), last 3 × 2 min. A bout can be won by knockout or point advantage [3]. Kickboxers are, therefore, required to have an optimal motor and technical skills level and be able to perform specific tactical actions during the fight [4]. However, an important element in sports competition is the body mass and body composition of the athletes and the correct ratios of anthropometric characteristics [5]. These aspects do not only determine the competition with opponents of a similar level of somatic predispositions (i.e., division into weight classes), but also ensure an optimal basis for mastering and using fighting techniques during competition [6]. The adequate level of body composition (i.e., low body fat with the body mass close to the upper threshold for the given class) and the right length ratios may indicate the athlete's aptitudes and determine his or her sports success [6,7]. In the world of modern sport, body composition monitoring is a basic activity that allows for the evaluation of body changes resulting from practicing a particular sport and determining its participation as the basis for sports selection [8]. The necessity to compete in a sport with weight classes such as K1 rules also requires kickboxers to regularly control their weight and body composition. Based on the diagnosed parameters of body composition, it is possible to precisely determine training (e.g., to develop the range of techniques used and the tactical way of fighting) and a nutritional plan (i.e., to optimize body mass and composition) for kickboxers [8]. Before taking part in sports competition, athletes often strive to gain the lowest possible body mass in order to qualify for a lower weight category in relation to their individual potential depending on body build [9]. In combat sports, athletes often dehydrate to quickly reduce weight during a pre-tournament weigh-in [10].

A K1 kickboxing fight has been reported to induce high physiological stress [11]. Kickboxers are prone to injuries, especially to the head and neck [12]. A longer kickboxing practice creates a risk of pituitary hormone-secretion impairment (hypopituitarism), which manifests itself in decreased concentrations of growth hormone, ACTH, and IGF-I [13]. A single fight in kickboxing, just as in boxing, is an effort in which anaerobic and glycolytic processes are the source of energy, which is indicated by the high concentration of blood lactate [14,15]. Apart from the significant acidification after a kickboxing fight, large changes in hormone concentrations, especially cortisol and growth hormone, similar in winning and losing competitors, have also been reported [16]. During exercise, about 75% of the energy expended is heat and 25% is mechanical work. As a result, mechanical work is accompanied by an increase in body temperature, which depends on the intensity, duration of work, and external conditions and the possibility of heat release into the environment. The energy expended for heat production during the competitive effort has been estimated in athletes of different sports. In boxers, the level of this energy exceeds 1000 watts [17]. The heat exchange during a short but very intensive effort such as a kickboxing bout can be one of the determinants of the level of cognitive abilities and, consequently, the course of the fight. For this reason, it may, therefore, be important to determine skin temperature and pH during kickboxing bouts, as these parameters have not yet been determined for kickboxing in the K1 style. The results of the examination may provide answers regarding the cutaneous changes and body responses caused by the kickboxing bout and the related punches and kicks. The human body is warm-blooded and, through thermoregulatory processes, maintains a constant temperature regardless of changes in the ambient temperature [18,19]. Maintaining a relatively constant body core temperature is a prerequisite for the efficient functioning of the organs, including the activity of enzymes that control metabolism. The most constant temperature is in the right ventricle, while the highest temperature, apart from the heart, is in the liver, brain, and brown adipose tissue [20]. The thermal balance in skeletal muscles varies over a very wide range, with the amount of heat released increasing during work and decreasing at rest [21]. At rest, muscles generate heat depending on their contraction maintained by nerve impulses [22]. Skin temperature (ST) varies over a wide range on the body surface, especially in cold environments and during exercise [23]. Hot water, surfactants, or mechanical actions lead to the damage to the skin's protective barrier or disturbance of the pH level [24]. The skin is protected and, therefore, it can effectively protect the inside of the human body when its pH remains at its natural level, allowing for a healthy balance of bacterial flora to be maintained [25].

The pH of the skin ranges between 4.5 and 5.5 [26]. In resting conditions, it was around two, but increased up to above five as a response to exercise [27,28]. In contrast, blood pH values are always much higher, even following intensive exercise. This is due to the buffer system that neutralizes the effects of lactic acidosis [28]. An alkaline pH facilitates the spread of bacteria throughout the epidermis, promotes the growth of pathogenic strains, and encourages the growth of bacteria that contribute to the unpleasant smell of sweat [29]. An acidic pH helps to keep the number of microorganisms at an appropriate level, increases the activity of bactericidal proteins and lipids, and facilitates proper skin keratinization and exfoliation, and wound healing [30]. Therefore, it is important to determine the local temperature at specific locations on the body surface and the pH level. An interesting issue is also the search for relations between skin temperature and its pH and the values of indicators of technical preparation.

A review of the literature on body composition and physiological variables in martial arts and combat sports reveals a lack of comprehensive analyses of body composition and cutaneous responses during fights in martial arts and combat sports. Research is often devoted to the aspects of proper hydration and the consequences of dehydration in sports [31]. The limits of dehydration and its consequences have also been explored [32]. Silva et al. [33] determined the body composition and power changes in elite judo athletes and confirmed the important role of proper hydration in judo competitions. The anthropometric characteristics and body composition of karate players at different sports skill levels have been also determined [34]. Scientific research on kickboxing has been mainly concerned with physiological and biochemical aspects [35–37]. Partial time-motion analyses of a kickboxing fight have also been conducted [38]. Previous research suggests that in addition to body mass, body composition may also be related to performance during athletic competition [39]. Additionally, the level of technical skills can be affected, to some extent, by the physique and body proportions of the athletes. For example, athletes with long limbs gain an advantage over their rivals by increasing the range of their attacks [6,40]. The literature review revealed the lack of studies in the context of measuring skin temperature and acidity during kickboxing competitions and linking body composition to indices of technical and tactical skill levels.

Thus, the present study aimed to verify the body composition of athletes, their skin temperature and its acidity during a kickboxing K1 rules competition and also the level of the technical and tactical skills of the athletes in relation to body composition, weight category, and skin pH and temperature. We hypothesized that the temperature and pH of the skin change with each round of combat as a result of direct skin contact with blows delivered by the opponent.

2. Materials and Methods

2.1. Participants

Twenty-four male kickboxers (Age range: 19 to 28 years), from different weight classes −71, −75, −81, −86, −91, and +91 kg, competing in a K1 kickboxing league volunteered to participate in the study. The inclusion criterion was primarily the sports' skill level, which was determined based on training experience of at least 6 years including 4 years of active participation in competitions and informed consent to participate in the study. A detailed description of the participants divided into weight categories is presented in Table 1. The athletes were participating regularly in kickboxing tournaments for more than 2 years. The rank of the tournaments is varied. The athletes compete both at a low level (category C), a middle level (category B), and a high level (category A). For the purpose of this study, category A athletes were analyzed. They were also all assigned to the same training regimen four times per week (1.5 h per session). Athletes did not present any medical restrictions during the experimental period and refrained from any strenuous exercises for 48 h before the experimental sessions started. Furthermore, subjects were not advised to follow a special diet and were asked to refrain from all forms of additional supplementation. The dietary assessment of the experimental group was based on the interview method. The respondents kept records in a notebook where they noted the foods, dishes, and drinks consumed on a daily basis. Without weighing, they recorded portion sizes using home measures based on a photo album of produce and dishes provided. The recording procedure was performed for 3 days: 2 working days, 1 day off [41].

Table 1. Characteristics of athletes in each weight category.

Weight Classes of Athletes	N	Age	Body Mass	BMI	%
−71 kg	4	23.0 ± 4.24	68.9 ± 1.09	21.37 ± 0.21	16.7%
−75 kg	4	21.75 ± 2.75	73.9 ± 0.44	22.26 ± 0.49	16.7%
−81 kg	4	21.25 ± 2.21	78.92 ± 1.35	24.89 ± 0.53	16.7%
−86 kg	4	21.5 ± 2.65	85.05 ± 1.18	25.8 ± 0.29	16.7%
−91 kg	4	21.3 ± 2.21	89.0 ± 1.20	26.03 ± 0.32	16.7%
+91 kg	4	23.0 ± 3.74	91.92 ± 0.58	26.58 ± 1.20	16.7%
Total	24	21.95 ± 2.82	81.28 ± 8.39	25.99 ± 2.04	100.0%

N—number of observations; %—percentage. Source: author's own elaboration.

Analysis of dietary records showed no special diets or use of nutrients and supplements to enhance exercise in the training groups. Control of diet and supplementation helped exclude factors that could significantly interfere with the results of the experiment. The body mass of the participants ranged from 67.9 to 92.6 kg (mean: 81.3 ± 8.38 kg). Body fat percentage measured for the participants was estimated at a mean level of 14.09% and ranged from 5.8 to 27.0%. Furthermore, the level of muscle tissue of the participants ranged from 55.8 to 75.0 kg, with a mean of 65.12 kg. The mean bone mass was 3.46 kg, and its variation was found to be between 2.9 and 3.9 kg. Body mass index (BMI) of the participants ranged from 21.4 to 27.17 kg/m^2, with a mean of 24.59 kg/m^2. Body water content in the athletes studied was determined at a mean level of 63.46%, with the obtained values ranging from 56.1 to 69.4%.

Prior to participation in the tests, the competitors were informed about the research procedures, which were in accordance with the recent ethical principles of the Declaration of Helsinki (WMA, 2013). Athletes provided written informed consent after the explanation of the aims, benefits, and risks of the study. The research was approved by the Bioethics Committee at the Regional Medical Chamber (No. 287/KBL/OIL/2020).

2.2. Procedures

The examinations were conducted during a local kickboxing tournament that was refereed. The bouts were held based on K1 rules in accordance with the regulations of the World Association of Kickboxing Organizations (WAKO) and lasted for three rounds of 2 min each. The breaks between rounds lasted 1 min, and the measurements were made during this time (Figure 1). The tournament hall was equipped with an air conditioning system to keep a constant ambient temperature (20–21 °C) and humidity (50–52%) throughout the study.

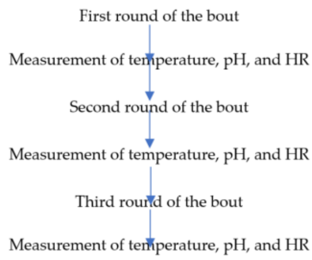

Figure 1. Research design.

2.3. Sparring Bout Analysis

The analysis of the sports fight was performed by two champion-level kickboxing coaches and one referee based on digital video recordings of the examined athlete. The recording was made with three cameras. Movavi Video Editor 14 software (Movavi, Wildwood, MO, USA) was used to merge the images. The setting of cameras allowed continuous observation of the athletes, referees, and the scoreboard. After the competition, the indices of attack activeness (A_a), which represents the ratio of all offensive actions used during the fight, attack effectiveness (E_a), which is the ratio of scoring techniques to all attacks used, and attack efficiency (S_a), which is the number of attacks scored, were calculated using established equations from the literature [2,4,42].

Activeness of the attack (A_a)

$$A_a = \frac{\textit{number of all registered offensive actions of a kickboxer}}{\textit{number of bouts fought by a kickboxer}}$$

Effectiveness of the attack (E_a)

$$E_a = \frac{\textit{number of efective attacks}}{\textit{number of all attacks}} \times 100$$

An effective attack is a technical action awarded a point.
Number of all attacks is a number of all offensive actions.
Efficiency of the attack (S_a)

$$S_a = \frac{n}{N}$$

n—number of attacks awarded 1 pt.
In K1 formula, each fair hit is awarded 1 pt.
N—number of bouts.

2.4. Biomedical Measurements

2.4.1. Skin Temperature Measurement

Skin temperature was measured using a professional Skin-Thermometer ST 500 (Khazaka Electronic Germany) in degrees Celsius (°C). The measurement was performed using a special lens and an IR detector by measuring the infrared radiation (IR) emitted by the skin. Measurements were taken before the bout, and after the first, second, and third rounds. The measurement site was previously wiped with a dry towel. The single measurement time was 2 s.

2.4.2. Skin/Sweat pH Measurement

Skin surface acidity was measured using the Skin-pH- Meter PH 905 (Khazaka Electronic Germany). Both skin temperature and pH measurements were taken at the following locations: forehead, chest, arm, hand, thigh, shank, and foot. After the measurements were completed for an individual, the probe was cleaned. The measurement time was one second.

2.4.3. Heart Rate Measurement

Heart rate (HR) during a bout was also measured using a chest strap (Garmin HRM-PRO) and a specialized watch Garmin Fenix 6x pro (Garmin, Olathe, KS, USA). The strap was worn after each round of the fight to determine the heart rate at the end of the round.

2.5. Body Composition Analysis

Body composition was determined using the electrical bioimpedance technique using the Tanita Bc 601 body composition analyzer before the tournament, from 6 to 8 am during the weigh-in before the competition. Body mass, body fat, muscle tissue, bone mass, BMI, DCI, metabolic age, and body water content were determined. All parameters were automatically calculated using the measuring device.

2.6. Statistical Analysis

Descriptive statistics (mean, median, minimum and maximum values, first and third quartile values, and standard deviation) were calculated for all variables. Statistical analysis was performed using the statistical software package Statistica for Windows (version 13.1; Tulsa, OK, USA). The normality of data sets was checked and confirmed using the Shapiro–Wilk W test. The correlations between two variables with normal distribution (activeness of the attack, effectiveness of the attack, body mass, muscle tissue level, DCI) were determined using Pearson's linear correlation coefficient, whereas for variables not meeting the criterion of normal distribution (efficiency of the attack, body fat %, bone mass, BMI, metabolic age, body water %), Spearman's rank correlation coefficient was calculated. Changes in skin temperature, HR, and pH over time were evaluated using Friedman's ANOVA. The level of statistical significance was set at $p < 0.05$. To control type-I error for multiple comparisons, Bonferroni procedure for correction of p-value has been used.

3. Results

The activeness of the attack in the athletes studied was estimated to range from 61 to 129 points, with a mean of 100.04 points. The efficiency of the attack was between 43 and 69 points, with a mean of 53.63 points. The effectiveness of the attack was at a mean level of 54.42 points, and it ranged from 40 to 69 points (Table 2).

Table 2. Level of indices of technical and tactical skills of athletes.

Index	Descriptive Statistics							
	N	Mean	Med.	Min.	Max.	Lower Quartile	Upper Quartile	Std. Deviation
Activeness of the attack	24	100.04	100.50	61.00	129.00	89.50	116.50	18.36
Efficiency of the attack	24	53.63	50.50	43.00	69.00	46.50	60.50	8.07
Effectiveness of the attack	24	54.42	56.00	40.00	69.00	47.50	59.50	8.09

N—number of observations; $\bar{x}$—arithmetic mean; Me—median; Min—minimum; Max—maximum; Q1—lower quartile; Q3—lower quartile; SD—standard deviation.

Statistical analysis confirmed the presence of statistically significant relationships between the activeness, effectiveness, and efficiency of the attack, and most anthropometric characteristics of the athletes (Table 3). For other correlations, the higher activeness, efficiency, and effectiveness of the attack correlated with a lower body mass of athletes, lower body fat percentage, lower body fat, lower BMI, DCI, metabolic age, and higher body water percentage (all $p < 0.05$) (Table 3). There was an unexpected positive correlation between the effectiveness of attack and the variable obtained from the aggregation of the individual pH involving four time points and seven places on the body's surface. This suggests that the more alkaline the skin is, the higher the index of effectiveness of attack is (Table 3).

Significant correlations were found between the selected anthropometric characteristics and the weight classes. There were positive relationships of weight class with body mass, body fat percentage, muscle tissue level, BMI, DCI, and metabolic age (Table 4). The value of the above-mentioned parameters increased in the athletes with the higher weight class. There was a statistically significant, negative correlation between the weight class and body water content in the athletes studied. Those performing in the higher weight classes had a lower body water percentage. Furthermore, there were also negative relationships of the activeness, efficiency, and effectiveness of the attack with weight class (Table 4).

Table 3. Evaluation of relationships between indices of technical and tactical skills and anthropometric characteristics (n = 24).

Variables	Activeness of the Attack		Efficiency of the Attack		Effectiveness of the Attack	
	r/R	p	r/R	p	r/R	p
Body mass	**−0.88**	**<0.001**	**−0.87**	**<0.001**	**−0.82**	**<0.001**
Body fat %	**−0.67**	**<0.001**	**−0.80**	**<0.001**	**−0.75**	**<0.001**
Muscle tissue	**−0.80**	**<0.001**	**−0.66**	**<0.001**	**−0.60**	**0.002**
Bone mass	−0.33	0.110	−0.13	0.556	−0.16	0.462
BMI	**−0.94**	**<0.001**	**−0.83**	**<0.001**	**−0.75**	**<0.001**
DCI	**−0.59**	**0.003**	−0.27	0.195	**−0.45**	**0.029**
Metabolic age	**−0.62**	**0.001**	**−0.66**	**<0.001**	**−0.67**	**<0.001**
Body water content (%)	**0.61**	**0.001**	**0.69**	**<0.001**	**0.65**	**0.001**
Mean skin pH	0.28	0.284	**0.42**	**0.039**	**0.43**	**0.043**
Mean skin temperature	0.17	0.424	0.14	0.051	0.5	0.813

BMI: body mass index, DCI: daily calorie intake, r—Pearson linear correlation; R—Spearman's rank correlation; p—test probability; values in bold are statistically significant. Source: author's own elaboration.

Table 4. Evaluation of the relationship of effectiveness and anthropometric characteristics with weight class (n = 24).

Variables	R	p
Body mass vs. weight class	**0.99**	**<0.001**
Body fat % vs. weight class	**0.78**	**<0.001**
Muscle tissue vs. weight class	**0.73**	**<0.001**
Bone mass vs. weight class	0.26	0.218
BMI vs. weight class	**0.93**	**<0.001**
DCI vs. weight class	**0.53**	**0.008**
Metabolic age vs. weight class	**0.74**	**<0.001**
Body water % vs. weight class	**−0.73**	**<0.001**
Activeness of the attack vs. weight class	**−0.94**	**<0.001**
Efficiency of the attack vs. weight class	**−0.87**	**<0.001**
Effectiveness of the attack vs. weight class	**−0.84**	**<0.001**

R—Spearman's rank correlation; p—test probability; values in bold are statistically significant. Source: author's own elaboration.

The mean temperature dropped with each round of the bout on the chest, arm, and thigh. On the hand and foot, the skin temperature increased with each round (Table 5).

Table 5. Descriptive statistics for temperature after warming up (WU) and three successive rounds.

Temperature	N	Mean	Confidence: −95%	Confidence: +95%	Med.	Min.	Max.	Lower Quartile	Upper Quartile	Std. Deviation
Forehead (WU)	24	31.92	31.35	32.49	32.50	30.00	33.40	30.00	32.99	1.34
1	24	30.52	29.87	31.16	30.60	27.40	32.80	29.70	31.00	1.53
2	24	30.73	30.11	31.34	31.40	28.30	32.30	29.40	32.10	1.45
3	24	31.13	30.68	31.58	31.10	29.20	32.60	30.45	31.80	1.07
p	**Chi^{2}Anova = 20.35, p < 0.001, η square = 0.988**									
Chest (WU)	24	29.53	29.07	29.98	30.00	27.40	31.00	28.85	30.20	1.09
1	24	27.34	26.92	27.75	27.80	25.40	28.60	26.75	27.90	0.98
2	24	26.38	26.08	26.67	26.70	25.10	27.30	25.90	26.80	0.70
3	24	25.85	25.29	26.41	26.00	24.10	28.00	24.20	27.00	1.32
p	**Chi^{2}Anova = 56.60 p < 0.001, η square = 0.998**									

Table 5. *Cont.*

Temperature	*N*	Mean	Confidence: −95%	Confidence: +95%	Med.	Min.	Max.	Lower Quartile	Upper Quartile	Std. Deviation
Arm (WU)	24	29.23	28.86	29.60	29.50	27.70	30.40	28.55	30.00	0.88
1	24	27.85	27.31	28.38	28.10	26.10	29.80	26.30	28.60	1.27
2	24	26.96	26.31	27.61	27.30	24.70	28.80	25.20	28.70	1.54
3	24	26.71	26.23	27.19	26.70	24.70	28.10	26.00	28.10	1.13
p	**Chi^2Anova = 53.69 *p* < 0.001, η square = 0.987**									
Hand (WU)	24	30.17	29.43	30.91	30.40	28.00	32.60	28.10	31.90	1.75
1	24	30.23	29.52	30.94	31.50	28.10	31.90	28.60	31.80	1.68
2	24	30.73	30.12	31.35	31.50	28.90	32.40	29.20	32.30	1.45
3	24	31.41	30.75	32.08	30.70	29.70	34.10	30.00	32.70	1.57
p	**Chi^2Anova = 28.29 *p* < 0.001, η square = 0.991**									
Thigh (WU)	24	29.58	29.25	29.92	29.70	28.20	30.70	29.00	30.20	0.79
1	24	27.78	27.38	28.18	27.90	25.80	28.90	27.30	28.70	0.95
2	24	27.34	26.72	27.95	27.30	25.20	30.00	26.10	27.60	1.45
3	24	27.06	26.44	27.68	26.80	25.30	29.50	25.70	28.20	1.46
p	**Chi^2Anova = 49.05 *p* < 0.001, η square = 0.997**									
Shank (WU)	24	29.14	28.86	29.43	29.20	27.70	30.10	29.00	29.50	0.67
1	24	27.68	27.36	28.01	27.90	26.30	28.90	27.20	28.20	0.77
2	24	27.10	26.78	27.43	27.00	25.50	28.10	26.90	27.75	0.77
3	24	27.21	26.91	27.52	27.20	25.80	28.20	26.80	28.00	0.73
p	**Chi^2Anova = 57.88 *p* < 0.001, η square = 0.999**									
Foot (WU)	24	24.98	24.03	25.92	24.00	23.10	29.70	23.20	26.90	2.24
1	24	25.06	24.19	25.93	25.00	23.00	29.60	23.35	25.90	2.07
2	24	25.74	24.54	26.93	26.00	21.30	30.00	23.20	27.60	2.83
3	24	26.03	25.05	27.00	25.30	22.50	29.50	24.90	28.50	2.30
p	Chi^2Anova = 6.85 *p* = 0.077, η square = 0.108									

p—test probability; values in bold are statistically significant η square-effect size.

The highest pH was recorded on the forehead in the measurement after the third round of the bout, while the lowest was found for the thigh at baseline. The acidity on the arm, hand, thigh, and shin increased with each round of the bout. However, it decreased on the foot and forehead in the next two rounds (Table 6).

Table 6. Descriptive statistics for pH after WU and following successive rounds.

pH	*N*	Mean	Confidence: −95	Confidence: +95%	Med.	Min.	Max.	Lower Quartile	Upper Quartile	Std. Deviation
forehead (WU)	24	6.23	6.13	6.33	6.22	5.80	6.48	6.09	6.43	0.24
1	24	5.86	5.73	5.99	5.92	5.40	6.28	5.61	6.13	0.31
2	24	6.11	5.91	6.31	5.96	5.35	6.79	5.83	6.62	0.47
3	24	6.55	6.37	6.72	6.69	5.92	7.02	6.01	6.90	0.42
p	**Chi^2Anova = 30.55 *p* < 0.001, η square = 0.992**									
chest (WU)	24	5.81	5.74	5.88	5.87	5.51	5.97	5.68	5.96	0.17
1	24	5.65	5.43	5.86	5.83	4.91	6.30	5.10	6.11	0.51
2	24	5.90	5.64	6.16	5.92	4.93	7.01	5.38	6.04	0.62
3	24	6.20	5.97	6.44	6.21	5.31	7.16	5.76	6.52	0.57
p	**Chi^2Anova = 36.45 *p* < 0.001, η square = 0.993**									

Table 6. *Cont.*

pH	N	Mean	Confidence: −95	Confidence: +95%	Med.	Min.	Max.	Lower Quartile	Upper Quartile	Std. Deviation
arm (WU)	24	5.58	5.44	5.72	5.69	4.89	5.89	5.32	5.89	0.33
1	24	5.68	5.44	5.93	6.03	4.83	6.27	5.11	6.22	0.57
2	24	5.86	5.54	6.18	5.91	4.84	7.17	5.25	6.16	0.75
3	24	6.13	5.81	6.44	6.02	5.14	7.55	5.66	6.32	0.75
p	**Chi^2Anova = 40.85 *p* < 0.001, η square = 0.994**									
hand (WU)	24	5.99	5.86	6.11	6.01	5.62	6.44	5.69	6.23	0.30
1	24	6.07	5.87	6.27	6.11	5.39	6.80	5.66	6.42	0.48
2	24	6.12	5.84	6.40	6.19	5.21	7.21	5.59	6.55	0.66
3	24	6.24	6.00	6.48	6.08	5.53	7.26	5.81	6.47	0.57
p	**Chi^2Anova = 13.85 *p* = 0.003, η square = 0.388**									
thigh (WU)	24	5.49	5.37	5.61	5.47	5.13	5.90	5.22	5.78	0.27
1	24	5.66	5.40	5.93	5.77	4.87	6.73	5.04	5.91	0.63
2	24	5.74	5.42	6.06	5.58	4.87	7.12	5.11	6.04	0.76
3	24	5.85	5.50	6.20	5.79	4.85	7.38	5.21	6.05	0.83
p	**Chi^2Anova = 11.25 *p* = 0.010, η square = 0.319**									
shank (WU)	24	5.55	5.42	5.67	5.59	5.11	5.93	5.34	5.78	0.29
1	24	5.57	5.33	5.82	5.62	4.51	6.40	5.26	5.82	0.58
2	24	5.66	5.28	6.05	5.43	4.67	7.43	5.00	6.04	0.91
3	24	5.86	5.54	6.17	5.67	4.95	7.17	5.25	6.31	0.75
p	**Chi^2Anova = 12.10 *p* = 0.007, η square = 0.330**									
foot (WU)	24	5.91	5.71	6.12	5.68	5.52	6.87	5.62	6.20	0.48
1	24	5.66	5.41	5.90	5.54	4.99	6.83	5.28	5.72	0.58
2	24	5.74	5.50	5.99	5.47	5.07	6.82	5.29	6.03	0.58
3	24	6.11	5.78	6.44	5.92	5.25	7.63	5.57	6.36	0.78
p	**Chi^2Anova = 38.45 *p* < 0.001, η square = 0.993**									

p—test probability; values in bold are statistically significant.

The HR values increased in the subsequent rounds of the fight, with its peak value of 184.63 bpm (Table 7).

Table 7. Descriptive statistics for heart rate (HR) measurements following warm-up (WU) and successive rounds.

HR	N	Mean	Confidence: −95%	Confidence: +95%	Med.	Min.	Max.	Lower Quartile	Upper Quartile	Std. Deviation
WU	24	116.96	111.13	122.79	117.00	103.00	148.00	104.00	119.50	13.81
First round	24	179.50	177.03	181.97	181.00	172.00	190.00	174.00	183.00	5.85
Second round	24	183.33	181.20	185.46	185.00	175.00	190.00	179.00	187.00	5.04
Third round	24	184.63	182.03	187.22	188.00	174.00	191.00	181.00	190.00	6.13
p	**Chi^2Anova = 59.27 *p* < 0.001, η square = 0.999**									

p—test probability; values in bold are statistically significant.

Statistically significant correlations were demonstrated between skin temperature and pH on the chest after the first, second, and third rounds of the bout. Significant correlations were also shown after the first and second rounds on the arms. Single correlations also occurred on the shank after the second round of the bout and foot after the third round. Furthermore, numerous correlations were shown between the lower and upper limbs, chest, and arm (Table 8).

Table 8. Relationship between pH and temperature (n = 24).

		Temperature						
		Forehead	**Chest**	**Arm**	**Hand**	**Thigh**	**Shank**	**Foot**
pH	forehead (WU)	**−0.82**	**−0.60**	−0.24	**−0.51**	**−0.73**	−0.22	−0.16
	1	0.28	**−0.45**	**−0.68**	0.40	**−0.57**	−0.02	−0.31
	2	0.19	**−0.93**	**−0.73**	**0.49**	**−0.42**	−0.33	**0.53**
	3	−0.16	0.05	**−0.76**	0.24	**−0.50**	−0.18	0.21
	chest (WU)	0.39	0.14	−0.32	0.01	**0.55**	−0.22	−0.31
	1	**0.46**	**−0.45**	**−0.68**	0.33	**−0.57**	−0.28	−0.13
	2	0.40	**−0.97**	**−0.83**	0.39	**−0.53**	−0.39	**0.46**
	3	0.17	**−0.51**	**−0.68**	**0.45**	**−0.54**	0.05	**0.55**
	arm (WU)	**0.50**	0.22	−0.07	−0.16	0.35	**−0.41**	**−0.50**
	1	**0.54**	−0.20	**−0.43**	0.25	**−0.42**	−0.29	−0.13
	2	**0.77**	**−0.62**	**−0.43**	0.01	−0.34	**−0.59**	0.19
	3	**0.65**	**−0.87**	−0.16	**0.42**	−0.25	−0.24	0.18
	hand (WU)	**0.72**	**0.70**	**0.54**	0.34	**0.43**	0.29	0.07
	1	**0.64**	−0.22	**−0.57**	0.40	**−0.71**	**−0.51**	−0.35
	2	**0.62**	**−0.67**	**−0.70**	0.06	**−0.68**	**−0.68**	−0.02
	3	**0.70**	**−0.96**	−0.24	**0.53**	**−0.44**	**−0.48**	−0.04
	thigh (WU)	**0.92**	0.17	0.15	**0.52**	−0.02	−0.12	0.25
	1	**0.52**	−0.12	−0.25	0.07	−0.16	−0.31	0.09
	2	**0.66**	**−0.44**	−0.32	−0.09	−0.36	**−0.45**	0.04
	3	0.35	**−0.78**	−0.18	0.27	−0.33	−0.22	0.05
	shank (WU)	**0.97**	0.16	0.05	**0.65**	0.13	−0.11	0.38
	1	0.15	0.02	−0.07	0.04	**−0.45**	−0.37	−0.25
	2	**0.60**	**−0.58**	**−0.43**	−0.11	−0.39	**−0.43**	0.13
	3	**0.43**	**−0.83**	−0.05	0.35	−0.31	−0.27	−0.04
	foot (WU)	**0.78**	0.04	0.16	0.41	0.40	−0.36	0.16
	1	0.04	−0.32	**−0.43**	0.16	**−0.81**	**−0.48**	−0.40
	2	**0.58**	**−0.82**	**−0.77**	0.13	**−0.63**	**−0.51**	0.20
	3	0.31	**−0.78**	**−0.41**	0.32	**−0.64**	**−0.75**	**−0.41**

Values in bold are statistically significant.

There was a statistically significant correlation between the pH of the forehead skin surface and HR after the first, second, and third rounds of the bout. The relationship between HR after the third round of the bout and the pH of the chest skin surface was also significant. There was a statistically significant correlation between the thigh temperature and HR at baseline.

4. Discussion

The purpose of this study was to comprehensively determine the body composition, skin temperature, and skin pH during a real kickboxing bout in K1 style and to establish the relationships of technical and tactical skills with body composition and weight classes. The results showed significant correlations between individual body composition parameters (body mass, body fat %, muscle tissue, BMI, DCI, metabolic age, body water %) and weight class that occurred in almost measured parameters. This result showed that the lower the weight class was, the lower the muscle and body fat was in the athletes. Similarly, lighter athletes were characterized by lower BMIs and DCIs. Kickboxing is a sport characterized by weight divisions where the competitor must meet certain body mass limits [6]. A negative correlation was found between the body water percentage and the weight class, which may also explain the limits associated with a specific weight class. Athletes often aim to compete in the lowest possible weight class by reducing their body mass and often inducing dehydration [43]. The present paper determined the level of technical and tactical skills of the athletes by analyzing their kickboxing fights according to K1 rules. Technical and tactical indices are the most precise tool used to determine athletes' behavior in combat sports [4]. The statistical analysis showed a negative correlation between the weight classes and the level of technical and tactical skills of the athletes. This result can be explained by the fact that lighter competitors are characterized by greater dynamics during combat, with a greater variety and frequency of techniques used. Similar conclusions were reported by previous studies analyzing judo bouts, which highlighted technical variation in relation to specific weight classes [44,45]. Our results indicate differences in the skill used by weight category. They do not unequivocally indicate the level of these skills, but they can indicate the fact that depending on the weight category, different technical patterns dominate; lighter athletes fight faster using more techniques and heavier athletes use fewer techniques.

Our research showed that a low level of body fat and muscle tissue significantly correlates with the activeness, effectiveness, and efficiency of the attack. The body fat percentage measured among the kickboxers was estimated at a mean level of 14.09%, ranging from 5.8 to 27%. The body fat increase was connected with a heavier weight class, in which the athletes were characterized by a higher body mass and lower activeness during the fight, which translated into other performance indices (effectiveness and efficiency). Furthermore, the mean fat percentage in athletes in the present study showed an optimal range according to the accepted norms [46,47]. The body fat percentage found in the present study was similar to that reported in a previous study of boxers, where body fat ranged from 9 to 16% [48]. This may indicate a convergence in the desired low levels of body fat in representatives of both sports. A detailed analysis of the examination conducted on kickboxing athletes revealed that a low body fat percentage is a prerequisite for athletes' high sports performance [6]. Likewise, athletes' muscle tissue level in the present study was found to have an average of 65.12 kg. Muscle development is related to both genetic predisposition and the training process, which shapes mainly the leg, arm, and abdominal muscles [49]. However, scientific studies confirmed that contact sports' competition induced significant muscle fatigue and damage [50]. Therefore, optimal muscle development is essential to obtain successful performance during combat, especially for technical and tactical actions [2].

Our study showed changes in skin temperature during the fights. Regular decreases in ST were found on the chest, arm, and thigh following each round of the kickboxing fight. The decrease in skin temperature in these areas may have been related to the evaporation of excess sweat, which is an endothermic process. Hence, sweating of the skin surface is considered the most effective way for the dissipation of excess heat in the human body that appears during prolonged and/or intensive exercise [51]. A decrease in temperature can also be caused by the changed blood flow due to compensatory vasoregulation [52,53]. In this consideration, Barboza et al. [34] assessed the skin temperature of middle-distance runners during maximal exercise and showed a decrease in the upper body area's temperature, while it was increased in the upper limbs due to solicited muscles [54]. In the present study, increased skin temperature was found on the feet, which may be due to metabolic heat generation or stress [55]. During exercise, blood flow increases in order to oxygenate the tissues, and therefore, temperature may increase [56]. It should be stressed that strenuous exertion, an elevated body or ambient temperature are not the only causes of an increased rate of sweating. Strong emotions, fear, and so-called psychological stress are independent factors leading to sweating, as has been found in pianists prior and post their official performance [57].

The pH analysis of the skin showed an acidic reaction in each case. After the first round of the fight, the pH level relative to the previous measurement slightly decreased on the forehead, chest, and foot, but after the third round, it increased over the initial value. This behavior might by related to changes in chemical substances in sweat such as hydrogen ions donors, lactic acid, or their acceptors, such as ammonia [58,59]. Measurements of pH in other points of the body also showed an increase between the rounds and the resting value. Searching the other reasons for this phenomenon, it is worth emphasizing that the human body has two types of sweat glands (eccrine, apocrine), which produce sweat in different amounts, directly affecting the pH [59].

For heart rate measurements, our results showed that values increased in exercise between the baseline and the first round, which may suggest the presence of anaerobic glycolysis. Previous research reported that kickboxing fights caused substantial physiological stress [11]. Our results showed a negative correlation between skin temperature and skin pH on the chest and arm, which indicated an increase in skin temperature at lower pH values. Statistical analysis revealed a correlation between the heart rate after the first round and the pH of the skin on the forehead, which was increased. In the remaining rounds of the bout, the pH value for the forehead decreased with higher HR values, which can be explained by an anaerobic metabolism and high body acidification [11].

The increase in HR in successive rounds reflects the increase in activity of the autonomic nervous system (ANS). The same behavior of the HR was noted during the boxing fights [58]. This response of the cardiovascular system and, indirectly, the nervous system may have influenced changes in both temperature and pH in our study. The mechanism of these relationships has been discussed above.

Limitation of the Study

In the present study, heart rate was measured by wearing a measuring strap after each round. Therefore, we were not able to record the maximum heart rate during the bout. The judges did not allow the strap to be worn during the entire bout for safety reasons. An additional difficulty during the examination was the profuse perspiration, and therefore, the need to wipe the examination site. Additionally, we did not have possibility to examine athletes from all the weight categories and female athletes.

5. Conclusions

Kickboxers who compete in lower weight classes are likely to be characterized by higher technical and tactical skills. The level of body fat and muscle tissue can affect the level of technical and tactical performance. The skin temperature changed with each round of the fight, and a temperature decline was noted in the large muscle groups (chest, arm, thigh) as the fight progressed. A kickboxing fight according to K1 rules led to skin pH changes after each round of the bout in the study group.

In conclusion, it should be emphasized that the directions of pH and temperature changes observed on the skin's surface during exercise may be very different from those occurring inside the body that were well described in the literature. Advanced techniques for measuring physiological changes on the skin have only recently become available to researchers; therefore, the small number of similar experimental studies published to date do not fully explain the physiological mechanisms of the observed phenomena.

Practical Implications

In kickboxing, body composition should be constantly monitored because the measured values can affect the course of the fight and the level of technical and tactical skills. Further research should also be conducted to clarify the physiological changes of the skin's surface during combat.

Author Contributions: Conceptualization, Ł.R. and T.A.; methodology, Ł.R., T.A. and Z.O.; software, Ł.R., T.A. and W.B.; validation, Ł.R. and T.A.; formal analysis, Ł.R., T.A. and Z.O.; investigation, Ł.R. and T.A.; resources, Ł.R., T.A. and I.O.; data curation, Ł.R., T.A. and W.B.; writing—original draft preparation, Ł.R., T.A. and I.O.; writing—review and editing, Ł.R., T.A. and I.O.; visualization, Ł.R. and T.A.; supervision, Ł.R., T.A. and I.O.; project administration, Ł.R. and T.A.; funding acquisition, Ł.R. and T.A. All authors have read and agreed to the published version of the manuscript.

Funding: Open Access was financed by the program of the Minister of Science and Higher Education, entitled 'Regional Initiative for Perfection', for the years 2019–2022 (Project No. 022/RID/2018/19; a total of PLN 11,919,908).

Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki, and approved by the Bioethics Committee at the Regional Medical Chamber (No. 287/KBL/OIL/2020).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Conflicts of Interest: The authors declare no conflict of interest.

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Załącznik nr 6

Rydzik, Ł.; Mardyła, M.; Obmiński, Z.; Więcek, M.; Maciejczyk, M.; Czarny, W.; Jaszczur-Nowicki, J.; Ambroży, T. Acid–Base Balance, Blood Gases Saturation, and Technical Tactical Skills in Kickboxing Bouts According to K1 Rules. *Biology (Basel).* **2022**, *11*, 65, doi:10.3390/biology11010065.

https://www.mdpi.com/2079-7737/11/1/65 (dostęp 27.01.2023 r.)

biology

Article

Acid–Base Balance, Blood Gases Saturation, and Technical Tactical Skills in Kickboxing Bouts according to K1 Rules

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Citation: Rydzik, Ł.; Mardyła, M.; Obmiński, Z.; Więcek, M.; Maciejczyk, M.; Czarny, W.; Jaszczur-Nowicki, J.; Ambroży, T. Acid–Base Balance, Blood Gases Saturation, and Technical Tactical Skills in Kickboxing Bouts according to K1 Rules. *Biology* **2022**, *11*, 65. https://doi.org/10.3390/biology11010065

Academic Editors: Filipe Manuel Clemente, Georgian Badicu, Eugenia Murawska-Ciałowicz and Paulo Gentil

Received: 6 December 2021
Accepted: 31 December 2021
Published: 2 January 2022

Simple Summary: The aim of our study was to analyze the changes in ABB after a three-round kickboxing fight and the level of technical and tactical skills presented during the fight. Fighting in kickboxing under K1 rules takes place with a high presence of anaerobic metabolism. Kickboxing athletes must have a good tolerance for metabolic acidosis and the ability to conduct an effective duel despite ABB disorders. Properly developed post-workout regeneration also plays an extremely important role.

Abstract: Background: Acid–base balance (ABB) is a major component of homeostasis, which is determined by the efficient functioning of many organs, including the lungs, kidneys, and liver, and the proper water and electrolyte exchange between these components. The efforts made during competitions by combat sports athletes such as kickboxers require a very good anaerobic capacity, which, as research has shown, can be improved by administering sodium bicarbonate. Combat sports are also characterized by an open task structure, which means that cognitive and executive functions must be maintained at an appropriate level during a fight. The aim of our study was to analyze the changes in ABB in capillary blood, measuring levels of H^+, pCO_2, pO_2, HCO_3^-, BE and total molar CO_2 concentration (TCO_2), which were recorded 3 and 20 min after a three-round kickboxing bout, and the level of technical and tactical skills presented during the fight. Methods: The study involved 14 kickboxers with the highest skill level (champion level). Statistical comparison of mentioned variables recorded prior to and after a bout was done with the use of Friedman's ANOVA. Results: 3 min after a bout, H^+ and pO_2 were higher by 41% and 11.9%, respectively, while pCO_2, HCO_3^-, BE and TO_2 were lower by 14.5%, 39.4%, 45.4% and 34.4%, respectively. Furthermore, 20 min after the bout all variables tended to normalization and they did not differ significantly compared to the baseline values. Scores in activeness of the attack significantly correlated (r = 0.64) with pre–post changes in TCO_2. Conclusions: The disturbances in ABB and changes in blood oxygen and carbon dioxide saturation observed immediately after a bout indicate that anaerobic metabolism plays a large part in kickboxing fights. Anaerobic training should be included in strength and conditioning programs for kickboxers to prepare the athletes for the physiological requirements of sports combat.

Keywords: acid–base balance; kickboxing; metabolic acidosis

1. Introduction

Acid–base balance (ABB) is a major component of homeostasis, which is determined by the efficient functioning of many organs, including the lungs, kidneys, and liver [1,2], and the proper water and electrolyte exchange between these components [3]. At rest, an equilibrium is maintained between the pulmonary gas pressures (pO_2 and pCO_2) in the human body, and the buffering system in the blood consists of hydrogen ion (H^+) acceptors, which include bicarbonate ions (HCO_3^-), proteins, amino acids, hydrogen phosphate ions (HPO_4^{2-}), and hemoglobin contained in erythrocytes. The buffering system compensates for small fluctuations in acidity, but intense exercise disrupts ABB in the body. Studies using 31P nuclear magnetic resonance spectroscopy have demonstrated a significant intracellular increase in H^+ concentration and a concomitant decrease in phosphocreatine (PCr) concentration during some seconds of repeated supramaximal exercise [4]. With buffering, the post-exercise blood H^+ concentration is much lower than in the cytosol. The peripheral and central chemoreceptors responsible for the regulation of the pulmonary ventilation rate respond to post-exercise changes in pH and disturbances in gas parameters of ABB [5,6]. Studies have shown that the higher the intensity of anaerobic exercise, the higher the blood levels of lactate and hydrogen ions and the greater the decrease in HCO_3^- [7–13].

It is believed that the temporary high acidification of cytosol in muscle fiber cells is not the only cause of the decrease in maximal power [14]. Nevertheless, numerous studies have confirmed that an increase in blood buffering capacity after oral administration of sodium bicarbonate or other alkalizing fluids reduces post-exercise pH disturbances and increases exercise capacity [15–21].

Exercise during competitions in combat sports such as kickboxing, boxing, taekwondo, and wrestling requires very good anaerobic capacity, which, as demonstrated by studies, can be improved by administering sodium bicarbonate [22–24]. Combat sports are also characterized by an open task structure, which means that cognitive functions must be maintained at an appropriate level during a fight [25]. The following cognitive abilities have been most often studied in combat sport athletes because the levels of these features are in a great part related to athletic skills. The most frequently tested cognitive functions in athletes are visuo-motor coordination [26–28], information processing and planning [29,30], and accuracy of decision-making [31]. It should be noted that in hitting sports, such as boxing and kickboxing, testing of cognitive functions matters for assessment of brain micro-injuries among athletes [32,33]. In laboratory tests, measurements of the speed and accuracy of reactions to visual stimuli are used to evaluate the level of some of the above-mentioned skills, including simple reaction tests, choice reaction tests, GO/NOGO tasks, Stroop tests, and trail making tests. Many published results have indicated a relationship between the level of performance during these tests and the physiological responses induced by various laboratory efforts. Immediately after intense exercise-induced metabolic acidosis, the results of the reaction time test and Stroop test are worse than at rest, but after a 15 min rest, they partially normalize [34]. Combined with concurrent psychometric testing, exercise tests do not fully replicate the task structure of a typical real fight. In most cases, the scale of difficulty in completing a mental and physical task during official combat sports competitions is much greater compared to laboratory psychophysical tests.

The experiments conducted in these studies demonstrated bidirectional changes in the level of performance during psychometric tests in response to laboratory test exercises of increasing intensity. These are fundamental to understanding the relationships between exercise intensity and physiological responses with level of performance of psychometric tasks. During the first phase of low-intensity exercise, the choice reaction time progressively decreases until a blood lactate concentration of 5.5 mmol/L is reached, and progressively increases once this concentration is exceeded [35]. A similar biphasic pattern of choice reaction time has been recorded during running with increasing speed [36]. Furthermore, higher levels of cognitive function are presented by individuals with a higher physical capacity [37]. In the case of psychometric tests that examine simultaneously the speed and accuracy of reactions using the GO/NOGO test, there is a need to choose between two contradictory decisions, one favoring speed and the other oriented towards accuracy. It has been demonstrated that the choice between these options may depend on the task structure of the sport.

Studies have shown that karate athletes prefer a higher speed of response to a stimulus but make more mistakes, while rowers do the opposite [31]. In this study, both groups demonstrated improved performance on psychometric tests in subsequent attempts. This phenomenon is known as the effect of learning a response to the same repeated stimuli [38]. In the case of executive functions used during fighting with an opponent the athlete does not know yet, there is a very large variety of stimuli and many choices of responses to them, which minimizes the learning effect observed during repeated laboratory testing. For this reason, in addition to physical fitness, the outcome of the competition is determined by the level of technical and tactical skills.

There have been few attempts to numerically assess the level of specific executive functions as a technical skill. Three basic parameters that characterize the level of performance during a real kickboxing bout have been developed and implemented [32,33,39,40]. The literature to date lacks a comparison of the assessment of such technical skills with measurements of physiological responses during competitions in combat sports, with athletes using fist punches and/or kicks. Ass mentioned earlier, boxing, kickboxing and taekwondo athletes are exposed to head injuries during competitions, which can reduce cognitive and executive abilities and impair technical skills [41,42]. In addition, three repeated maximal physical efforts may contribute to physiological changes [43,44], which are, in part, responsible for accumulation of fatigue. The most visible symptom of increasing fatigue during successive bouts may be an increasing number of pauses and total time of pauses [45]. Although the analysis of the used types of offensive actions and their number during kickboxing matches have been presented in the literature, the novel skill parameters as a mirror of the levels of cognitive–executive function, together with complex physiological responses to the contest, are lacking. Thus, the aim of our study was to analyze the changes in ABB after a three-round kickboxing bout and the level of technical and tactical skills presented during the bout.

2. Materials and Methods

The study involved 14 kickboxers presenting the highest sports skill level (champion level).

The sports skill level was evaluated based on sporting achievements and having a kickboxing master's degree, and the coach's opinion. The minimum training experience of the subjects was between 8 and 10 years. The participants were aged 19 to 35 years. Details of the study group are presented in Table 1.

Table 1. Anthropometric measures of study participants.

Variables	No	M	Me	Min	Max	Q1	Q3	SD
Body mass	14	84.90	85.50	75.00	90.00	83.00	88.50	4.93
Body height	14	181.05	180.00	175.00	189.00	179.00	183.50	3.39
BMI	14	26.04	25.99	24.12	28.64	25.15	26.73	1.24

No—number, M—mean, Me—median, Min—minimum, Max—maximum, Q1—first quartile, Q3—third quartile, SD—standard deviation.

2.1. Analysis of the Fight

The competitors had one bout each according to K1 rules in the morning after two days of a training break. The fights were held according to the rules of the World Association of Kickboxing Organizations (WAKO) and consisted of three 2-min rounds separated by 1-min rests.

The fights were simulated, but took place on neutral ground and were refereed by a qualified referee. The athletes were matched in a manner consistent with their weight category.

The determination of the technical and tactical performance parameters was made based on video recordings of the bouts. Subsequent analysis was conducted using specialized formulas [40,46,47].

The efficiency of the attack indicates a number of scored points influencing the final result of the bout compared to the number of bouts observed.

Efficiency of the attack (S_a)

$$S_a = \frac{n}{N}$$

n—number of attacks scoring 1 point.
* In K1 rules, each clean hit of the opponent scores 1 point
N—sum of observed bouts ($N = 1$ in this study)

The effectiveness of the attack denotes the number of scoring techniques compared to all the offensive actions performed.

Effectiveness of the attack (E_a)

$$E_a = \frac{number\ of\ effective\ attacks}{number\ of\ all\ attacks} \times 100$$

An effective attack is a technical action awarded a point
Number of all attacks is a number of all offensive actions

The activeness of the attack describes the engagement of the athlete, indicating the number of offensive actions performed during the observed fights.

Activeness in the attack (A_a)

$$A_a = \frac{number\ of\ all\ registered\ offensive\ actions\ of\ a\ kickboxer}{number\ of\ fights\ fought\ by\ a\ kickboxer\ (1\ in\ this\ study)}$$

2.2. Acid–Base Balance Analysis

ABB parameters were analyzed using an EPOC gasometer (Siemens, Ottawa, ON, Canada) immediately after 95 µL of arterialized fingertip blood was drawn into glass capillaries containing calcium-balanced lithium heparin (65 IU/mL). The determinations were made 5 min before the bout (measurement I), and 3 min (measurement II) and 20 min after the bout (measurement III).

Hydrogen ion concentration (H^+), partial pressure of oxygen (pO_2), and partial pressure of carbon dioxide (pCO_2) were measured, and base excess in the extracellular fluid (BEecf) concentration of bicarbonate ions HCO_3^- and TCO_2 (total molar carbon dioxide concentration) were calculated.

2.3. Bioethics Committee

Prior to participation in the tests, the competitors were informed about the research procedures, which were in accordance with the ethical principles of the Declaration of Helsinki WMADH (2000). Obtaining the competitors' written consent was the condition for their participation in the project. The research was approved by the Bioethics Committee at the Regional Medical Chamber (No. 287/KBL/OIL/2020).

2.4. Statistical Analysis

Statistica 13.1 software (StatSoft, Cracow, Poland) was employed for statistical analysis. Friedman's ANOVA test was used to compare the results of repeated measures. The post-hoc test was Dunn's test. Correlation analysis between selected variables was performed using Pearson's linear correlation test. The Shapiro–Wilk test was used to test data for normal distribution. Effect size was calculated according to the formula:

Kendall's W = Chi $^{2/}$N(K − 1), N = sample size, K = number of measurements. The level of statistical significance was set at $p < 0.05$.

3. Results

The biochemical indices studied changed significantly during the bout and recovery. The greatest changes were observed after the second measurement (3 min after the bout) (Table 2). For pCO_2, the difference was significant only between measurements I and II, for H^+, pO_2, HCO_3^- between measurements I and II and between measurements II and III, and for BE between all measurements (Table 2).

Table 2. The level of acid–base balance parameters in the tested group of athletes in three consecutive measurements.

Parameter	Measurement									Friedman's ANOVA		Post-Hoc (Dunn's Test)	Effect Size
	I (*n* = 14)			II (*n* = 14)			III (*n* = 14)						
	M	Me	SD	M	Me	SD	M	Me	SD	Chi^2	*p*	I-II	I-II
H^+ (nmol/L)	37.9	37.0	3.3	54.0	49.0	9.8	41.1	40.0	3.9	22.29	<0.001	<0.05	0.80
pCO_2 (mmHg)	37.2	37.3	3.3	31.8	31.9	2.6	35.2	35.0	0.7	7.43	0.024	<0.05	0.27
pO_2 (mmHg)	77.2	75.2	6.0	85.6	85.1	8.5	73.9	75.8	4.5	16.15	<0.001	<0.05	0.58
HCO_3^- (mmol/L)	24.6	25.3	1.3	14.9	15.4	1.6	21.3	21.6	1.8	24.57	<0.001	<0.05	0.88
BE mmol/L	0.5	0.9	1.2	−11.9	−10.6	2.7	−3.7	−3.2	2.4	28.00	<0.001	<0.05	1.00
TCO_2(mmol/L)	24.1	25.1	1.3	15.8	16.1	1.4	21.5	21.7	1.1	24.50	<0.001	<0.05	0.88

M—mean, Me—median, SD—standard deviation. NS—not statistically significant, I—before exercise, II—3 min after exercise, III—20 min after exercise.

In most cases, the differences between measurements I and II were highest. They were also relatively high between measurements II and III, while the smallest (non-significant) differences were observed between measurements I and III (Table 2).

The recovery rate 20 min after the end of the bout was highest for H^+ and was 96.97 ± 45.94%, whereas for the other ABB parameters the rate reached 68.57 ± 18.44% for HCO_3^- and 68.30 ± 13.62% for BE.

The activeness of the attack was evaluated at a mean level of 96.9 ± 43.6 and the range of scores was from 68 to 198. For the efficiency of the attack, it was a mean score of 50.1 ± 12.8, and ranged from 37 to 79, whereas for the effectiveness of the attack, it was a mean of 54.5 ± 7.9, ranging from 39.9 to 64.5 (Table 3).

Table 3. Value of activeness, efficiency, and effectiveness of the attack.

Variables	No	M	Me	Min	Max	Q1	Q3	SD
Activeness of the attack	14	96.9	79.0	68.0	198.0	76.0	96.0	43.6
Efficiency of the attack	14	50.1	47.0	37.0	79.0	45.0	49.0	12.8
Effectiveness of the attack	14	54.5	54.4	39.9	64.5	49.0	60.8	7.9

There were no significant correlations between the changes in the parameters induced by the bouts for $[H^+]$, pCO_2, pO_2, HCO_3^-, BE (ecf), or BE (b). The only positive correlation was found between molar concentrations of CO_2 (TCO_2) and the activity of the attack, which suggests that the greater the physical activity, the greater rise of CO_2 concentration in the blood (Table 4).

Table 4. Matrix of correlation coefficients between examined variables.

Variables		Activeness of the Attack		Efficiency of the Attack		Effectiveness of the Attack	
		R	*p*	R	*p*	R	*p*
Δ = I-II	$[H^+]$	0.11	0.62	0.07	0.81	0.07	0.808
	pCO_2 (mmHg)	0.14	0.14	−0.03	0.90	0.00	1.00
	pO_2 (mmHg)	0.14	0.62	−0.32	0.26	−0.03	0.90
	HCO_3^- (mmol/L)	−0.21	0.46	−0.25	0.38	0.32	0.26
	BE (ecf) mmol/L	−0.10	0.71	−0.01	0.95	−0.41	0.13
	TCO_2 mmol/L	0.64	0.01	−0.32	0.26	−0.17	0.54

Valuesin bold are statistically significant

4. Discussion

The significant changes in ABB parameters and blood oxygen and carbon dioxide saturation immediately after the bout indicate a large contribution of anaerobic metabolism in generating the physical work and gas exchange rate in kickboxers. The examinations conducted by other authors in kickboxers immediately after each of three rounds or after an entire bout showed a significant decline in muscle strength, and a progressive increase in blood lactate levels and heart rates [43–45,48]. In our study there were very weak correlations between activity in attacks and rise of hydrogen ion levels, but a significant positive link between activity and post bout increase of total CO_2 level. That relationship may suggest relatively high mechanical efficiency in tested contestants, according to the model describing relationships between mechanical work output and metabolism [49]. As was mentioned earlier, kickboxing belongs to a family of hitting martial arts similar to Muay Thai, karate and taekwondo, where upper and lower limbs are engaged in offensive actions [50]. Practitioners of all these sports use the same techniques of punches and kicks. One of the most effective kicking techniques is the roundhouse kick, when it is performed correctly. Biomechanical factors of this kick have been explored and described in detail [51]. To date, the literature lacks data on ABB and gasometric studies after kickboxing bouts. Few and fragmented data on ABB and gasometry have been published after boxing fights [13]. This sport differs from kickboxing in its task structure and variety of attacks, but the requirements for general physical fitness, technical skills, and the type of attacks using the upper limbs are very similar. Bout intensity assessed based on lactate and post-exercise changes in magnitude and direction for ABB and gas saturation in boxers [13,22] are also consistent with our findings. We also conducted our ABB and gasometry observations during the short-term recovery period. The results showed that there were no statistically significant differences between baseline and post-exercise recovery measured at 20 min after the bout. However, the results showed that the normalization of parameters was not fully achieved, which indicates a deep disruption of homeostasis caused by the bout. Glycolytic metabolism exercise significantly decreases the levels of bicarbonate as a main factor in neutralizing hydrogen ions in the blood. This process occurs according to the following equation: $H^+ + HCO_3^- \rightarrow H_2O + CO_2 \uparrow$. Despite the increased release of carbon dioxide into the blood, its saturation decreased during the bout due to increased gas exchange in the alveoli and intensifying hyperventilation [52,53]. Decreases in blood pCO_2 and bicarbonate levels during intense exercise have also been reported by previous researchers. Similar post-exercise changes in ABB and blood gas parameters were noted in non-athletes and athletes, but a slight increase in oxygen saturation (by 14%) was observed only in athletes [54]. We found a similar (although slightly smaller, ca. 10%) increase in oxygen saturation after a kickboxing bout. This may suggest that regular physical training induces such an adaptive mechanism. It is important to mention that under resting conditions, hyperventilation is responsible for blood alkalization, since in the case of negligible lactate levels and the associated source of hydrogen ions, the main H^+ donor is the reversible reaction of $CO_2 + H_2O \leftrightarrow HCO_3^- + H^+$. It has been shown that short-term resting hyperventilation at a mean lactate concentration of 1.9 mmol/L leads to a decrease in the partial pressure of CO_2 to a mean value of 21 mmHg and significant blood alkalization (pH = 7.6, H^+ = 23 nmol/L). During competitions in combat sports, it is not possible to quantify the level of hyperventilation. We also did not measure the ventilation immediately before the bout. Hyperventilation attenuates the post-exercise decrease in pH, reduces CO_2 saturation, and increases anaerobic power, especially at the end of a set of efforts [55]. A beneficial effect of pre-exercise hyperventilation before a competition on short-distance swimming performance has also been reported [56]. The reduction in CO_2 saturation and hydrogen ion concentration due to hyperventilation improves physical performance during repeated resistance efforts [55]. Therefore, as documented, the beneficial effect of exercise-induced hyperventilation results from physiological responses. Blood alkalization obtained pharmacologically prior to graded exercise has been found to delay the onset of hyperventilation during work, which, according to researchers, confirms that lactate acidosis increases respiratory rate [57].

The appropriate level of cognitive functions is of great importance in open skill sports. The results of psychometric measurements, reaction time, and decision-making in female and male kickboxers have shown differentiation depending on sex and rules of competition (light vs. full contact) [58], but, to date, there has been no comparison of the results of laboratory psychometric tests with the assessment of executive functions, i.e., the technical performance during a real bout. The few studies conducted in kickboxers have only been designed to assess activeness during the bout. A slightly higher number of higher- and lower-intensity actions was demonstrated in light-category athletes [45] and a higher ratio of activity time to rest time was found in another study [59]. Noticeable differences have been reported in activity and offensive fighting style in winners and losers based on the number of combined punches, kicks, and alternating hand and leg actions [60].

5. Conclusions

1. The disturbances in ABB and changes in blood oxygen and carbon dioxide saturation observed immediately after a bout indicate that anaerobic metabolism plays a large part in kickboxing fights. Anaerobic training should be included in strength and conditioning programs for kickboxers to prepare the athletes for the physiological requirements of sports combat.
2. K1 kickboxers must be characterized by good metabolic acidosis tolerance and the ability to fight effectively despite ABB disturbances, and show good post-exercise recovery.

Author Contributions: Conceptualization, Ł.R.,T.A., M.M. (Mateusz Mardyła); methodology, Ł.R., T.A., M.M. (Mateusz Mardyła), Z.O.; software, Ł.R., T.A.; validation, Ł.R., T.A.; formal analysis, Ł.R., T.A., J.J.-N.; investigation, Ł.R., T.A., W.C.; resources, Ł.R., T.A., M.M. (Mateusz Mardyła), M.M. (Marcin Maciejczyk); data curation, Ł.R., T.A., M.W.; writing—original draft preparation, Ł.R., T.A., M.M. (Mateusz Mardyła), J.J.-N.; writing—review and editing, Ł.R., T.A., Z.O., M.M. (Marcin Maciejczyk), M.W.; visualization, Ł.R., T.A., M.W., M.M. (Marcin Maciejczyk); supervision, Ł.R., T.A., W.C., J.J.-N.; project administration, Ł.R.; funding acquisition, Ł.R., T.A., M.M. (Marcin Maciejczyk), W.C. All authors have read and agreed to the published version of the manuscript.

Funding: Open Access financed by the programme of the Minister of Science and Higher Education entitled'Regional Initiative for Perfection' within the years 2019–2022, project No. 022/RID/2018/19, in the total of 11919908 PLN.

Institutional Review Board Statement: The research was approved by the Bioethics Committee at the Regional Medical Chamber (No. 287/KBL/OIL/2020).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study are available on request from the corresponding author.

Acknowledgments: Thank you to all the fighters who made the survey research.

Conflicts of Interest: The authors declare no conflict of interest.

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Załącznik nr 7

Rydzik, Ł. Indices of Technical and Tactical Training During Kickboxing at Different Levels of Competition in the K1 Formula. *Antropomotoryka* . **2022**, *31*, 1–5, doi:10.5604/01.3001.0015.7542.

https://jkes.eu/resources/html/article/details?id=227922 (dostęp 27.01.2023 r.)

JKES Journal of Kinesiology and Exercise Sciences

Antropomotoryka. Journal of Kinesiology and Exercise Sciences
JKES 97 (32): 1-5, 2022

(1.1) DOI: 10.5604/01.3001.0015.7542

INDICES OF TECHNICAL AND TACTICAL TRAINING DURING KICKBOXING AT DIFFERENT LEVELS OF COMPETITION IN THE K1 FORMULA

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Authors' contribution:
A. Study design/planning
B. Data collection/entry
C. Data analysis/statistics
D. Data interpretation
E. Preparation of manuscript
F. Literature analysis/search
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Received: 06.12.2021
Revised: 23.12.2021
Accepted: 31.12.2021
Published: 02.01.2022

Keywords: Kickboxing, fight analysis, technical and tactical training indices

Abstract:

Background: Kickboxing is a combat sport with many variations in its competition. Fighting, according to K1 Rules, is characterised by the greatest freedom in terms of the number of allowed techniques and the strength of their execution. The objective of analysis was to determine indices of technical and tactical training (activity, efficacy, attack effectiveness) during a kickboxing fight according to K1 rules, carried out at various levels of competition.

Materials and methods: The study comprised 24 kickboxing fights, analysed according to K1 Rules. From the World Championships, National Championships and local tournaments, 8 fights were considered and analysed. The technical and tactical training indices were determined on the basis of formulas provided in the literature.

Results: Statistically significant changes in the level of technical and tactical training indices for fighters were demonstrated between the world championships, the national championships and the local tournament, $p<0.001$.

Conclusions: The highest values of the measured technical and tactical training indices occurred during the World Championships, while the lowest during the local tournament. The results of the research allow for a preliminary interpretation of the level of technical and tactical preparation during fights according to K1 rules.

Introduction

Kickboxing is a combat sport with many variations in its competition. Fighting, according to K1 Rules, is characterised by the greatest freedom in terms of the number of allowed techniques and the strength of their execution. All the techniques used in this sport are acceptable, without limiting the power of inflicting them [1]. In light of literature on the subject, kickboxing fights are increasingly becoming the object of much scientific research. Researchers are exploring the aspects of combat analysis in terms of physiological [2–5], physical fitness [6,7] and innovative determination of technical and tactical training indices [6–8]. By determining these indices, it is possible to diagnose a competitor's baseline skills. This type of analysis of the technical performance of athletes was initiated in Judo, where similar measurements are systematically made [9–13]. Inspired by the formulas specified for Judo, the formulas were adapted to the analysis of the kickboxing fight in the K1 formula. The relationship between the technical and tactical training indices and the offenses of the competitors during the fight was assessed [8]. It has been determined in detail which motor skills should be developed to increase activity, efficacy and effectiveness in combat [6]. The correlation between training indices and the body composition of athletes has been presented [5].

However, there is no existing assessment of technical and tactical training indices in kickboxing at various levels of competition. This type of verification was defined in Judo, where the values of the technical and tactical preparation level during the 2 most important championship events were compared [10].

The aim of this study is to assess the technical and tactical training indices at various levels of competition during a kickboxing fight according to K1 rules. This analysis will help to define the detailed level of competitor's baseline abilities, contributing to the improvement of quality in coaching control.

Materials and methods

Study design

The study included 24 kickboxing fights, analysed according to K1 Rules. From the World Championships, the National Championships and a local tournament, 8 fights were analysed. Only the final fights were assessed by calculating the technical and tactical training indices for the winners of each weight category: -63.5 kg, -67 kg, -71 kg, -75 kg, -81 kg, -86 kg, -91 kg and +91kg.

Technical and tactical analysis

Analysis of the sports competition was carried out on the basis of a digital register of the match. Taking this recording into account, the indices of technical and tactical training were determined according to the established formulas [2,6–8].
Efficiency of the attack (Sa)

$$Sa = \frac{n}{N}$$

n – number of offensive actions (attacks) scored by points, 1 pt
*According to K1 Rules, each clean hit, 1 pt
N – total of observed fights for given competitor
Effectiveness of the attack (Ea)

$$Ea = \frac{\text{number of effective offensive actions}}{\text{total number of offensive actions}} \times 100$$

* An effective offensive action (attack) is considered a technical action for which a point has been awarded
* The total number of offensive actions (attacks) is considered all attempts at offensive techniques
Activeness of the attack (Aa)

$$Aa = \frac{\text{number of registered of offensive for competitor}}{\text{number of combats fought by studies competitor}}$$

Statistical analysis

Statistical analysis of the collected material was carried out using the PQstat v1.8.2 program (PQStat Software, Poznań). The basic descriptive statistics were calculated: arithmetic mean, standard deviation, minimal and maximal values, and the level of the first and third quartiles. The Kruskal-Wallis ANOVA test was applied to assess the significance of differences for 3 variables, then, the post-hoc Bonferroni test was used to evaluated the significance of differences between individual levels of competition. The level of statistically significant differences was assumed as $p<0.05$.

Results

The attack activity index for individual levels of competition demonstrated statistically significant differences. The highest values were recorded at the World Championships and the lowest during the local tournament (Tab. 1).

The attack efficacy index for individual levels of demonstrated statistically significant differences. The highest value of the index was recorded successively during the World hcampionships, the National Championships and the local tournament (Tab. 2).

The attack effectiveness demonstrated statistically significant differences, its highest level being recorded during the World Championships, while its slightly lower was noted during the National Championships. The athletes competing during the local tournament showed the lowest effectiveness (Tab. 3).

Table 1. Values of attack activity index

Attack actvity	n	x̄	Min.	Max.	Q1	Q3	SD	NC	LT
World Championships (WC)	8	145.37	110	179	125	166.5	25.49	p=0.11	***p*<0.001**
National Championships (NC)	8	97.13	44,00	134,00	73.00	122.00	32.04	–	*p*=0.25
Local tournament (LT)	8	60.625	48.00	74.00	51.00	70.25	10.81	*p*=0.25	–
Anova *p*					***p*<0.001**				

n – number of studied subjects, Min – minimal value, Max – maximal value, Q1 – first quartile, Q3 – third quartile, SD – standard deviation, NC – National Championships, LT – Local tournament; statistically significant values are in bold

Table 2. Values of attack efficacy index

Attack efficacy	n	x̄	Min.	Max.	Q1	Q3	SD	NC	LT
World Championships (WC)	8	127.75	97	161	97.5	153.5	28.76	p=0.14	***p*<0.001**
National Championships (NC)	8	72.00	29.00	104.00	53.50	88.00	25.42	–	***p*=0.04**
Local tournament (LT)	8	27.44	16.66	42.85	20.26	34.52	10.30	**p=0.04**	–
Anova *p*					***p*<0.001**				

n – number of studied subjects, Min – minimal value, Max – maximal value, Q1 – first quartile, Q3 – third quartile, SD – standard deviation, NC – National Championships, LT – Local tournament; statistically significant values are in bold

Table 3. Values of attack effectiveness index

Attack effectiveness	n	x̄	Min.	Max.	Q1	Q3	SD	NC	LT
World Championships (WC)	8	87.28	77.6	92.99	82.08	92.23	6.33	p=0.11	***p*<0.001**
National Championships (NC)	8	71.70	52.27	79.31	67.81	77.58	9.06	–	p=0.06
Local tournament (LT)	8	11.75	6.00	23.00	7.50	15.50	6.27	***p*=0.06**	–
Anova *p*					***p*<0.001**				

n – number of studied subjects, Min – minimal value, Max – maximal value, Q1 – first quartile, Q3 – third quartile, SD – standard deviation, NC – National Championships, LT – Local tournament; statistically significant values are in bold

Discussion

In this work, the levels of technical and tactical training are assessed during kickboxing competitions carried out according to the K1 formula at various levels of competition.

In the evaluation of training, specialised formulas were used, which are reliable for assessing the level of technical and tactical skills of a competitor [2,5,7,8]. In measuring the attack activity of the subjects, the highest values were demonstrated for those fighting in the World Championships. This may be related to the highly-developed motor and technical capabilities. The athletes competing at the World Championships are the winners of national tournaments who demonstrate a professional level of training [1,14]. The average level of attack activity during the national Championships was 97.13 points, which was close to the values recorded during the analysis of 20 competitors demonstrating high sports level [6]. Fighting on the basis of K1 requires the competitor to execute accurate hits and kicks that will end the fight ahead of time due to 'knockout' [15]. Therefore, the high activity of athletes may indicate a fierce duel, accompanied by a frequent exchange of techniques. Additionally, the decrease in activity may be caused by worse fitness preparation, an activity necessary for effective fighting [2,16–18].

A similar trend was observed in the attack success rate, which was also the highest during the World Championships. A comparison of research results shows statistically significant differences between the efficacy of the attack during the World Championships and the local tournament, the difference of which was 100 points. The proper efficacy of an attack requires appropriate baseline experience and a developed level of physical fitness [6,7]. Competitors with more experience in competitions have a better developed reflexes and so-called timing, which allows to successfully make clean hits on the opponent [19].

Statistical analysis of the effectiveness index allowed to show statistically significant differences between the values achieved during the local tournament and the World Championship. In addition, the presented index demonstrates the lowest difference between the World and National Championships. The winners of the National Championships are called up to appear at the World Championships, therefore, a similar range of effectiveness may prove the high level of final competitions at the National Championships.

Limitations

The main limitation in this study was the small number of analysed fights, based solely on final competitions. The author of the work did not have access to more recorded fights in order more reliably determine the training indices for each level of competition. The original assumption of this study was to develop a scale to be able to interpret the indices of technical and tactical preparation, however, this requires broader analysis of the entire work, with a division into weight categories.

Conclusions

The indices of attack activity, efficacy and effectiveness turned out to be the highest during the competition at the World Championships, and the lowest during the local tournament. The smallest differences in the level of technical and tactical preparation of the competitors fighting at the World Championships, compared to this National, were shown in the attack effectiveness index. Further research should be carried out in which the ranges of these indices would be determined at a particular level of competition which, in turn, will enable the qualification of competitors immediately after the end of the fight.

Practical applications

Specific indices of technical and tactical training at different levels of competition can be used by researchers to make preliminary comparisons and interpret them based on the average values demonstrated in this study. Based on the results obtained for the best fighters, it is possible to designate training directions for weaker adepts for particular elements occurring during a fight.

Conflicts of Interest: The author declare no conflict of interest.

Funding: No funding reported

Institutional Review Board Statement: The research was approved by the Bioethics Committee at the Regional Medical Chamber (No. 287/KBL/OIL/2020).

Informed Consent Statement: Informed consent was obtained fromall subjects involved in the study.

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Citation:
Rydzik Ł: Indices Of Technical And Tactical Training During Kickboxing At Different Levels Of Competition In The K1 Formula. Antropomotoryka. Journal of Kinesiology and Exercise Sciences. 2022;97(32):1-5.

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Załącznik nr 8

Rydzik, Ł. Determination Of The Real Training Load Based On Monitoring Of K1 Kickboxing Bouts. *J. Kinesiol. Exerc. Sci.* **2022**, *100*, 1–8, doi:10.5604/01.3001.0016.0606.

https://jkes.eu/resources/html/article/details?id=232566 (dostęp 27.01.2023 r.)

JKES
Journal of Kinesiology and Exercise Sciences

Antropomotoryka ISSN: 1731-0652 E-ISSN: 2353-3986
Parallel title: Journal of Kinesiology and Exercises Sciences

100 (32): 1-8, 2022

(1.1) DOI: 10.5604/01.3001.0016.0606

DETERMINATION OF THE REAL TRAINING LOAD BASED ON MONITORING OF K1 KICKBOXING BOUTS

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Authors' contribution:

A. Study design/planning
B. Data collection/entry
C. Data analysis/statistics
D. Data interpretation
E. Preparation of manuscript
F. Literature analysis/search
G. Funds collection

Received: 02.09.2022
Revised: 27.09.2022
Accepted: 29.09.2022
Published: 5.10.2022

Keywords: Kickboxing, K1, heart rate, fight analysis, training load

Abstract:

Background: Kickboxing is a combat sport in which scientific observations are regularly made to improve the quality of the training process. Heart rate monitoring is the basic form of the evaluation of training load and diagnosing the athlete's capabilities. The purpose of this study was to determine training load based on heart rate measurements in K1 kickboxers.

Methods: The study was conducted on 18 kickboxers, with HR recorded over a 3-round kickboxing fight. HRmax level was calculated for each athlete according to the most recent formula. Based on these data, the percentage training load was determined according to the needs arising from the training periodization.

Results: The results of the study showed that training of K1 kickboxers is based primarily on submaximal heart rates, which increase with each round of the bout ($p<0.001$).

Conclusions: The training load for a K1 kickboxing bout based on maximum heart rate should be 95.44% HRmax in the first round, 96.23% HRmax in the second, and 97.01% HRmax in the round.

Introduction

Sports fight analysis is an important part of coaching supervision [1]. Observation of athletes allows for the evaluation of their activeness, efficiency, and effectiveness. In striking combat sports, coaches make regular observations and calculations of the number of techniques and their hits [2]. This helps coaches diagnose the athlete's technical and tactical capabilities and modify the training process [3]. Another element is to monitor heart activity by means of the measurement of the athlete's heart rate. This allows for the evaluation of the recovery rate and (indirectly) the athletes' physical capacity, which underlies general and special endurance [4]. This method of assessing the athlete's performance has been used primarily in running sports [5–8]and now there are attempts to adapt it to other sports, including combat sports [9]. According to numerous studies in the field of sports theory, the training load (especially the level of intensity) is often determined as %VO2max [10, 11]. In training practice, it is easier and more efficient to determine these levels by measuring the athlete's heart rate (HR), for example, using heart rate monitors.

Furthermore, more effective measurement of maximum heart rate can be performed using proven laboratory methods [12]. However, there are methods of estimating this level indirectly. They are used to determine HRmax under training or competitive conditions and are being constantly improved [13]. The most popular formula for determining maximum heart rate is 220-age [14], whereas Tanaka made a modification using the formula 208-(0.7*age) [13]. Recently, however, the formulas have undergone modifications and Lach et al. have recently developed the most accurate formula: 202.5–0.53*age [15].

Physiological analysis of the course of a kickboxing bout has been carried out many times [16–19], especially in K1 kickboxing, which is the most demanding and energetic variation of kickboxing fights [20]. There was also an analysis of changes in acid-base balance and total blood gas saturation during the fight [21]. The HR and lactate levels achieved by the athletes during a real kickboxing bout were determined [22, 23]. Slimani has repeatedly performed heart rate monitoring in combat sports [9, 24] to determine the physiological responses to this type of exercise. Heart rate measurements are also regularly performed in boxing [25, 26]. The exercise intensity was evaluated during simulated boxing fights [27]. Imamura conducted heart rate verification during a 20-round karate fight [28]. Also in this sport, physiological loads have been repeatedly measured in athletes during and after fights [29–31]. Similar analyses have been often made in taekwondo [32–34]. Furthermore, such examinations are regularly performed in soccer [35–38] and swimming [39, 40]. However, the literature is lacking in defining training loads based on HR levels in K1 kickboxing.

Therefore, the aim of this study was to deepen the knowledge of determining the training load based on heart rate measurements, for kickboxing athletes fighting in K1 rules formula.

Material and Methods

Study design

In the present study, the intensity of the training load during a K1 kickboxing fight was determined by monitoring the body's responses using heart rate measurements. Maximum heart rate was then calculated for each participant according to formulas pro-posed in the literature. The experiment was conducted according to the following design (Figure 1).

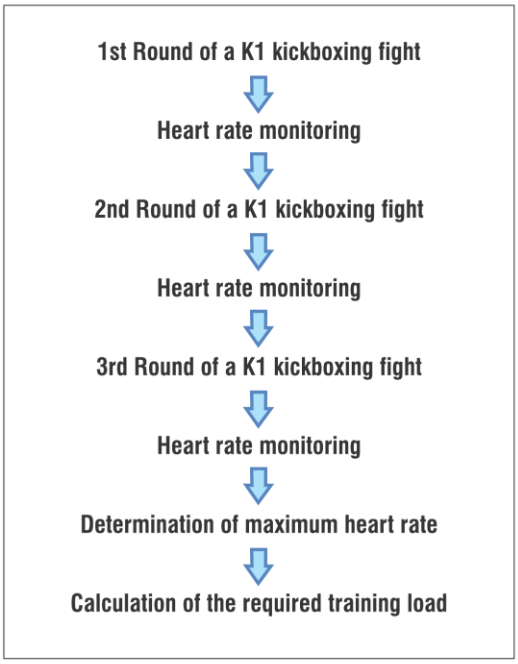

Figure 1. Study design

Participants

The study was conducted on a group of 18 kickboxers who regularly competed under K1 rules. The mean age of the participants was 22.94±2.33 years, with their mean training experience of 6.61±1.28 years. The selection of athletes was purposive based on the inclusion and exclusion criteria described in Table 1.

Table 1. Inclusion and exclusion criteria for the study

Inclusion criteria	Exclusion criteria
Training experience of at least 5 years	Training experience < 5 years
Regular participation in competitions	No participation in competitions
Good health status	Injuries
Consent to participate in the study	No consent to participate in the study
Male	Female
Minimum age: 18 years	Age <18 years

Measurement methods

Heart rate analysis was performed using a Garmin Fenix 6x pro heart rate monitor (Garmin, USA, Olathe) along with a Garmin HRM Pro chest strap (Garmin, USA, Olathe). All athletes fought a three-round kickboxing bout refereed under K1 rules. Each round lasted 2min, while the break between rounds was 1min. Prior to the fight, the athletes per-formed an individual warm-up according to the procedures they usually followed before the competitions. The fights were held in a neutral training room which was unfamiliar to the athletes. This was aimed to most closely simulate the competitive environment. Each fighter wore a chest belt throughout the fight. However, due to the dynamics of the fight, to avoid erroneous readings due to the belt slip, peak HR was recorded for the present study. The research was approved by the Bioethics Committee at the Regional Medical Chamber (No. 287/KBL/OIL/2020).

Determination of maximum heart rate

The maximal heart rate for each kickboxer was calculated using the latest maximal heart rate formula developed by Lach et al. [15]

$$HRmax = : 202.5 - (0.53 * age)$$

The spreadsheet was then used to calculate the percentage values recorded during the bout relative to HRmax.

Statistical analysis methods

Statistical analysis of the collected material was conducted in Statistica v13.3 soft-ware (Statsoft, Kraków, Poland). Basic descriptive statistics were calculated: arithmetic means, standard deviations, minimum, maximum, and value of the first and third quartile. Consistency of the variables with normal distribution was confirmed by the Shapiro-Wilk test. The significance of differences between the three measurements was calculated using a one-way analysis of variance (ANOVA) with repeated measures. The significance of differences between rounds (I vs II, II vs III, I vs III) was calculated using Tukey post-hoc test. The level of statistically significant differences was set at $p<0.005$. The effect size between the three measurements was calculated using eta-squared, whereas between rounds - using Cohen d. The results of the analysis are presented in tables and figures, including 95% confidence intervals.

Results

With each round, the athletes showed higher peak heart rates, which proved to be statistically significant ($p=0.00$) with the large effect size. Between the first and second rounds, and between the second and third rounds, the effect size was medium and the values were statistically significant $p<0.005$ (Table 2) (Figure 2).

Table 2. Peak heart rate values during a kickboxing fight under K1 rules

HR	Descriptive statistics										
	n	$\bar{x}$	Min.	Max.	Q1	Q3	SD	p1	p2	ES1	ES2
HR Peak 1st round	18	181.66	176.0	188.0	179.0	184.0	3.25	-	**0.003**	-	0.50
HR Peak 2nd round	18	183.16	178.00	189.0	182.0	185.0	2.79	**0.003**	-	0.50	-
HR Peak 3rd round	18	184.66	180.0	190.0	183.0	186.0	2.78	**<0.001**	**<0.001**	1.00	0.54
ANOVA					**p=0.00**		ES=0.99				

n– number of participants, x – arithmetic mean, min – minimum, max – maximum, Q1 – first quartile, Q3 – third quartile, SD – standard deviations, p– significance of differences, ES – effect size, p1 – statistical significance for the first measurement, p2– statistical significance for the subsequent measurement, ES1– effect size for the first measurement, ES2 – effect size for the subsequent measurement

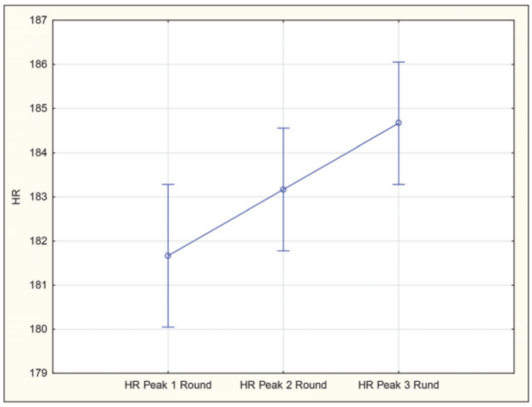

Figure 2. Peak heart rate in individual rounds of the fight

Vertical bars indicate 95% confidence intervals

Results of individual calculations of maximum heart rate for each athlete are shown in Table 3.

Table 3. Detailed description of the study group with calculations of maximum heart rate ac-cording to the formula

Athlete No.	Age (years)	HR max according to the formula by Lach et al. HRmax=202.5-(0.53* age)[15]
1	23	190.31
2	26	188.72
3	21	191.37
4	20	191.9
5	25	189.25
6	24	189.78
7	23	190.31
8	22	190.84
9	18	192.96
10	20	191.9
11	21	191.37
12	24	189.78
13	23	190.31

Continued Table 3.

Athlete No.	Age (years)	HR max according to the formula by Lach et al. HRmax=202.5-(0.53* age)[15]
14	23	190.31
15	24	189.78
16	23	190.31
17	27	188.19
18	26	188.72

In the first round, the athletes' percentage heart rate was 95.44% HRmax, with the level increasing to 96.23% HRmax in the second round and 97.01% HRmax in the third. These values were statistically significant (p=0.00) and characterized by large effect size (Table 4, Figure 3). The mean heart rate relative to the maximal heart rate in the entire bout was 96.22% HRmax.

Table 4. Percentage of heart rate relative to maximum heart rate

% HR	Descriptive statistics										
	n	$\bar{x}$	Min.	Max.	Q1	Q3	SD	p_1	p_2	ES_1	ES_2
After 1st round	18	95.44	92.48	98.30	94.58	96.43	1.61	-	**0.004**	-	0.51
After 2nd round	18	96.23	93.53	98.48	95.62	97.22	1.39	**0.004**	-	0.51	-
After 3rd round	18	97.01	94.58	99.00	96.15	98.28	1.32	**<0.001**	**0.003**	1.06	0.57
ANOVA					**p=0.00**		ES=0.99				

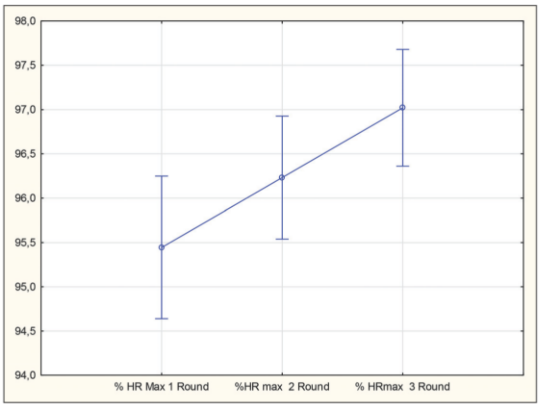

Figure 3. Percentage of heart rate during the fight relative to maximum heart rate

Discussion

An analysis of peak heart rate during a K1 kickboxing bout showed that the fighters reached a mean HR level of 181.66 bpm in the first round. Therefore, it can be concluded that they quickly reached submaximal HR, as it corresponded to 95.44% HRmax. Similar results were obtained in a physiological analysis of kickboxing fights, with the results indicating that the athletes relied heavily on anaerobic metabolism [22]. Interpretation of the results recorded in successive rounds lead to the conclusion of growing fatigue as illustrated by higher HR values. The high heart rate values recorded in the bout may be due to the specific K1 rules, in which techniques performed at full speed and strength are al-lowed [41, 42], consequently encouraging the athlete to maintain maximum concentration and commitment during the entire fight. Analysis of our results showed that athletes fight with a mean heart rate of 96.22% HRmax. The load they experience is higher than analyses that have been conducted using similar methods on judo [43, 44], taekwondo, karate, and Muay Thai [9] fighters. Repeated observations have proven that fighters in a kick-boxing bout often attempt to end the fight by knockout [20]. Consequently, each attack is performed with maximum effort. Exercise intensity manifested itself in high HR values maintained until the end of the bout. An official K1 fight lasts 3 times for 2 minutes, and therefore, due to the relatively short time of the bout, fighters are able to maintain a high disposition based on anaerobic metabolism throughout the fight. This has been confirmed in studies analyzing the indicators of technical and tactical performance in kickboxers. The results of these studies indicated that the athletes had high levels of activeness of the attack throughout the fight [3, 45, 46]. The present study was designed to present physio-logical responses to the load induced in fighters during a K1 kickboxing bout so that coaches can simulate competitive conditions during specialized endurance training.

Endurance is defined as the ability to use the biological potential of physical capacity while taking into account personality and mental capabilities such as motivation, willpower, and tolerance to fatigue [47]. Cardiorespiratory endurance is a type of endurance related to the ability to continue exercise conditioned by the efficiency of the cardiovascular and respiratory systems. Applying the loads at an intensity level of 96.22% HRmax during training offers an effective method of maintaining cardiorespiratory en-durance. It is also an important indicator of the correct implementation of peak loads during direct pre-competition preparation [11].

Limitation of the study

The present study was conducted using a chest strap to measure the heart rates of athletes. As a result of the dynamic fight and the appearance of sweat, the belt tended to slip. Therefore, the peak heart rate was used in the present study instead of its mean values for the entire round. Presenting mean values for a round would underestimate HR values, affecting the conversion of the load to values relative to maximum heart rate. Furthermore, maximum heart rate was evaluated using a formula used in the literature, which is an indirect method of determining HRmax and may be inaccurate.

Conclusions

Fighters in a kickboxing bout perform exercise at submaximal heart rates, which increase with each round. Our study showed that the exercise intensity of the training load in a K1 kickboxing bout relative to maximum heart rate should be 95.44% HRmax in the first round, 96.23% HRmax in the second, and 97.01% HRmax in the third. An overall mean level of 96.22% HRmax can be adopted as a training load during simulation practice that corresponds to the volume and intensity of an entire kickboxing bout.

Practical implication

The method of diagnosis and determination of training load intensity presented in this paper can be useful for coaches to quickly assess and individually adjust training loads in each athlete.

Funding: This research received no external funding

Institutional Review Board Statement: The research was approved by The Bioethics Committee at The Regional Medical Chamber (No. 287/KBL/OIL/2020).

Informed consent statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: All data are presented in the study.

Conflicts of Interest: The authors declare no conflict of interest

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Citation:
Rydzik Ł: Determination of The Real Training Load Based on Monitoring of K1 Kickboxing Bouts. Antropomotoryka. 2022;100(32):1-8.

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