Review

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A Systematic Review of Dynamic Forces and Kinematic Indicators in the Front and Roundhouse Kicks Across Varied Conditions and Participant Experience.

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A Systematic Review of Dynamic Forces and Kinematic Indicators in the Front and Roundhouse kicks Across Varied Conditions and Participant Experience

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Abstract: : Impact force and maximum velocity are important indicators of kick efficiency in fighting activities. Therefore, this systematic review compared the front kick (FK) and roundhouse kick (RK), including maximal and impact force, maximum velocity, maximum angular velocity, and execution time, at different target types and experience levels. The Web of Science, SportDiscus, and PubMed were systematically searched from January 1982 to May 2022, according to PRISMA guidelines. The normalized kicking values were compared using one-way ANOVA. Eighteen articles, including FK with a pooled sample of 113 elite men, 109 sub-elite men, and 46 novices, and 25 articles, including RK with a sample of 238 elite men, 143 sub-elite men, and 27 novice men, fulfilled the inclusion criteria. The primary findings were that the impact forces of FK were higher than RK for the novice, sub-elite, and elite groups by 47% ($p<0.01$), 92% ($p<0.01$), and 120% ($p<0.01$), respectively. Moreover, the maximum foot velocity of RK was faster than FK for the sub-elite and elite groups by 44% ($p<0.01$) and 48% ($p<0.01$), respectively. The Elite group had 65% ($p<0.01$) higher knee extension angular velocity within RK than FK, and 138% ($p<0.01$) higher hip extension angular velocity within FK than RK.

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1. Introduction

In the realm of fighting activities, such as martial arts, combat sports, and close combat, participants dedicate themselves to enhancing their strength, speed, and refining their techniques to overcome opponents or breaking solid target [1,2]. Biomechanics tools have proven instrumental in investigating and improving the techniques employed in these sports and combat activities, with researchers utilizing dynamic and kinematic indicators for thorough analysis [3,4]. However, as the number of studies continues to rise, researchers must consider the varying conditions under which combat techniques are performed. Consequently, comparing findings from previously published studies to establish defined qualities of kicking techniques is essential.

The kick is among the fundamental techniques employed in combat activities to overcome opponents, which requires maximum strength and speed. Previous research has often compared kicks to punches, as well as explored comparisons across experience levels, gender, and different fighting actions [5–11]. Notably, studies have examined kicks at various distances from the target, with different target types, and even under different carried military loads [12–17]. However, a notable gap exists in the comparison of the key characteristics between different types of kicks, explicitly focusing on the frequently reported front kick (FK) and roundhouse kick (RK).

Significant differences exist in the execution of FK and RK, particularly in the lower limb track and swing phases involving hip and knee coupling, particularly in terms of hip flexion and knee extension [18]. The FK entails a direct foot strike achieved through hip flexion and knee extension toward the opponent or target. Conversely, the RK involves a swinging arc of the hip and rapid knee

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extension to strike the target with the shin or instep. The technical execution of both kicks significantly influences accuracy, precision, and the ability to hit the target effectively [11,19], thereby relating to the performer's level of proficiency. Consequently, the performance level can be a fundamental differentiating factor for FK and RK's net force and kicking speed characteristics.

Net force and kicking speed characteristics play vital roles in overcoming or neutralizing an opponent's attack and are integral to determining the transferred momentum of energy [13,17,20–24]. These metrics offer valuable insights into the force production of a kick and contribute to a better understanding of its mechanics and effectiveness in combat sports and martial arts. Kicking speed, crucial for its efficacy, relies on factors such as execution time, which can often exceed the opponent's reaction, as well as reaction time itself [7,13,16,23]. Other variables include velocity, acceleration, and angular velocity of the hip and knee [7,16,25–30]. Therefore, it is desirable to compare the differences in net dynamic forces and kinematic indicators between the FK and RK across various performance levels and execution conditions.

Previous studies have examined FK and RK's dynamic forces and kinematic indicators under different conditions, including target distance, target type, and participants' experience. Therefore, this systematic review compares FK and RK regarding maximal and impact force, maximum velocity, maximum angular velocity, and execution time at different target distances, target types, and experience levels. Building upon previous studies, our hypothesis posits that FK and RK will significantly differ in impact force and maximum velocity at different target types and experience levels.

This review compares performance attributes FK and RK, explicitly focusing on practical use. There is an overview of the dynamic and kinematic differences within the different technical levels in connection with the different execution conditions of FK and RK.

2. Materials and Methods

This article presents a systematic review that follows the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) recommendations [31,32]. The review protocol was prospectively registered online with PROSPERO (registration number CRD42022332589).

Literature Search

A comprehensive database search was conducted from 1982 to May 19th, 2022, using Web of Science, SportDiscus, and PubMed. The search strategy included specific keywords for front kick (Mae-Geri and Apchagi) or roundhouse kick (Mawashi and Dollyo), formulated according to each database's requirements (see Supplementary Table 1). To ensure the inclusion of relevant articles, the reference lists of screened studies were also reviewed. The search was limited to articles written in English. All references were imported into Endnote X20 (Clarivate Analytics, USA), and duplicates were identified and removed.

Eligibility Criteria

To be included in the review, articles had to meet the following criteria: (i) they contained information on the front or roundhouse kick, (ii) they reported at least one of the dynamic forces or kinematic indicators (Maximum Force, Impact Force, Maximum Velocity, Angular Velocity, and Execution time), (iii) they involved male participants, and (iv) they provided participants' weight for calculating normalized outcomes when measuring dynamic forces. During the full manuscript screening, studies were excluded if (i) they reported the same results as another accepted study or (ii) they used simulation data instead of camera motion capture.

Study Selection

Two authors independently screened the titles and abstracts: the head combat instructor of the Czech Army (the first author) and the strength and biomechanics research expert (the last author). They decided which articles should be included in the full manuscript review. The first authors,

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together with the third and fourth authors, reviewed the full text of the selected articles. Any discrepancies or disagreements among the authors were resolved through discussion and consensus. If needed, the second author made the final decision regarding article inclusion.

Data Collection Process

After selecting the relevant studies, the first author created an evidence table that included study demographic data, types of kicks and fighting activities, equipment used to measure dynamic and kinematic variables, and the variables themselves (see Supplementary Table 2). The third and fourth authors independently verified all the collected data.

Assessment of Methodological Quality and Risk of Bias

The first and last authors assessed the risk of bias in all articles in the systematic review. Any disagreements were resolved through discussion and consensus or by the decision of the second author. A scale was developed based on selected items from the STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) Statement for observational studies [33], along with items created explicitly for this review. The assessment questions included: (1) Was the abstract an informative and balanced summary of the study? (2) Was the scientific background clearly explained? (3) Were the eligibility criteria, participant selection methods, and sources clearly stated? (4) Was the condition measured in a standardized and reliable manner for all participants? (5) Was the measurement of dynamic or kinematic indicators described in sufficient detail for replication? (6) Were any efforts to address potential bias described? (7) Were outcomes and conclusions clearly defined? The Cochrane Risk of Bias tool for the Generic dataset was used to display the risk of bias (see Supplementary Figure 1), where the judgment was represented by symbols indicating low risk of bias (+), some concerns (-), high risk of bias (x), or no information (?).

Data Treatment

The means and standard deviations of dynamic forces (maximum force and impact force and kinematic indicators (velocity, angular velocity, and execution time) were categorized based on the following criteria: experience level (elite, sub-elite, and novice), distance from the target, the height of the target, and stance position. The categorization rules were as follows:

xperience Level: Participants with a black belt or a combination of black and brown belts, international competitors, and head instructors of close combat in the army were classified into the elite group. Participants with martial art degrees at the pupil level, different levels of martial arts degrees with a predominance of pupil degrees, national competitors, or soldiers with regular close combat training were classified into the sub-elite group. Participants without experience in fighting activities were classified into the novice group.

Distance from the Target: The different distances from the target were divided into three groups: close distance (0.68 - 0.70 meters), middle distance (1 meter), and large distance (1.35 - 1.4 meters) [12,13].

Height of the Target: The different heights of the kick were divided into two groups: the middle group (kick to the torso of the body) and the height group (kick to the head).

Stance Position: The stance position chosen was where one leg is in front and the second leg is in the rear, and the kick was performed from the rear leg.

In studies that included an intervention program, data from the first session before the intervention were used for analysis. If the data in any of the studies were already normalized using the average weight of the participants, it was converted to the original units for descriptive statistics. To compare average values between groups (different levels of participants or target types, etc.), the values of dynamic forces were normalized by the weight of the probands.

Statistical Analysis

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Statistical analysis was performed using Statistica 14 (Tibco Software Inc., Palo Alto, USA) and Microsoft Excel (Microsoft Corporation, Redmond, Washington, USA). The significance alpha level was set at ≤0.05. Forest plots and graphs were created using GraphPad Prism version 8.0. The mean and standard deviation of the maximum and impact force of the front and roundhouse kicks were normalized by the participants' weight and weighted by the number of participants. Similarly, the mean and standard deviation of kick execution time, maximum velocity, and maximum angular velocity were also weighted by the number of participants. Forest plots were used to present the normalized weighted mean with a 95% confidence interval for dynamic variables and the weighted mean with a 95% confidence interval for kinematic variables. For comparison and effect size calculation, one-way ANOVA with Tukey post hoc test and Cohen's d were used. Levene's test was employed to assess data equality of variance. In cases where two variables were compared, the t-test was utilized.

3. Results

A total of 619 records were retrieved through individual searches of Web of Science, SportDiscus, and PubMed, and nine additional articles from referent list. After screening titles and abstracts and removing 94 duplicates, 129 articles remained. The full texts of these studies were assessed, and after objective assessment, 42 articles remained (one article contained the FK and RK); 18 articles included the FK and 25 included the RK (Figure 1). The records of the remaining 42 articles, which included a pooled sample of 113 elite men, 109 sub-elite men, and 46 novice men performing the FK, and 238 elite men, 143 sub-elite men, 27 novice men, three elite women, and two sub-elite women performing the RK were included for systematic review and divided into individual categories according to dynamic and kinematic variables.

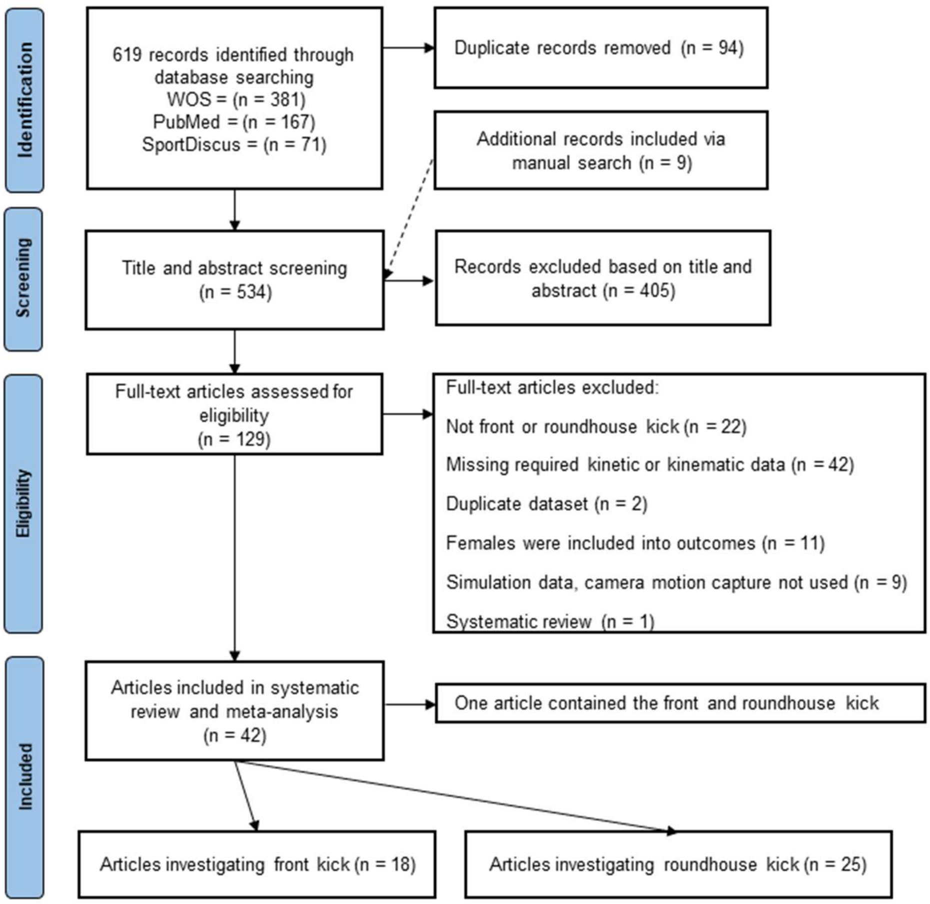

Figure 1. The flow chart of the systematic approach to the articles selection relevant to the Front and Roundhouse kicks.

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However, there was only enough data available to compare the levels of participants in terms of impact forces, the maximum velocity of the foot, knee, and hip, execution time, and maximum angular velocity of the knee and hip extension (Tables 1, Tables 2).

Table 1. Performance of the front kick (Mean and SD). .

Front kick	Novice	Sub-elite	Elite	Novice	Sub-elite	Elite
	Maximum Force (N)			**Impact Force (N)**		
Number of mean results	1	5	1	1	6	3
Number of participants	6	58	12	18	54	29
Participants' weight (kg)	74.3	82.6	86.9	80.5	81.5	77.7
Front kick (M ± SD)	3157 ± 291	5261 ± 1497	5869 ± 1763	1570 ± 362	2846 ± 805	3696 ± 1621
	The velocity of the foot (m/s) – Target			**The velocity of the foot (m/s) – Air**		
Number of mean results	1	11	10	-	2	1
Number of participants	16	127	103	-	22	1
Front kick (M ± SD)	7.7 ± 1.2	8.56 ± 1.08	9.61 ± 1.05	-	10.74 ± 1.01	12.25 ± 0.18
	The velocity of the knee (m/s) – Target			**The velocity of the knee (m/s) – Air**		
Number of mean results	1	5	5	-	1	1
Number of participants	16	67	47	-	6	1
Front kick (M ± SD)	5.3 ± 0.7	5.32 ± 0.62	5.88 ± 0.6	-	5.06 ± 1.19	6.32 ± 0.06
	The velocity of the hip (m/s) – Target			**The velocity of the hip (m/s) – Air**		
Number of mean results	1	5	3	-	-	-
Number of participants	16	67	45	-	-	-
Front kick (M ± SD)	2.1 ± 0.3	2.4 ± 0.49	2.39 ± 0.57	-	-	-
	Angular velocity of the knee (°/s) – Target Extension			**Angular velocity of the hip (°/s) – Target Extension**		
Number of mean results	-	3	2	1	3	2
Number of participants	-	28	36	6	28	18
Front kick (M ± SD)	-	934 ± 145	917 ± 191	427 ± 8	556 ± 90	536 ± 72
	Total execution time (s) – Target			**Total execution time (s) – Air**		
Number of mean results	-	1	3	-	-	1
Number of participants	-	12	29	-	-	1
Front kick (M ± SD)	-	1.140 ± 0.221	1.076 ± 0.099	-	-	0.950

Table 2. Performance of the roundhouse kick (Mean and SD).

Roundhouse kick	Novice	Sub-elite	Elite	Novice	Sub-elite	Elite
	Impact Force (N) close distance, middle height			**Impact Force (N) middle distance, middle height**		
Number of mean results	2	4	3	2	7	7
Number of participants	42	52	40	42	106	65
Participants' weight (kg)	75.6	74.2	74.9	75.6	70.7	79.7
Roundhouse kick (Mean, SD)	1204 ± 507	1333 ± 536	1705 ± 524	1007 ± 483	1227 ± 429	1656 ± 459
	Impact Force (N) large distance, middle height			**Impact Force (N) close distance, large height**		

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Number of mean results	2	4	3	1	1	2
Number of participants	42	52	40	21	14	25
Participants' weight (kg)	75.6	74.2	74.9	75.7	72	75
Roundhouse kick (Mean, SD)	864 ± 392	1101 ± 487	1456 ± 466	1121 ± 368	1327 ± 167	1641 ± 219
	Impact Force (N) middle distance, large height			**Impact Force (N) large distance, large height**		
Number of mean results	1	1	2	1	1	2
Number of participants	21	14	25	21	14	25
Participants' weight (kg)	75.7	72	75	75.7	72	75
Roundhouse kick (Mean, SD)	1053 ± 356	1469 ± 135	1605 ± 267	864 ± 361	1203 ± 154	1521 ± 249
	The velocity of the foot (m/s) – Target middle distance, middle height			**The velocity of the foot (m/s) - Air middle distance, middle height**		
Number of mean results	1	4	11	-	-	2
Number of participants	15	33	110	-	-	30
Roundhouse kick (Mean, SD)	6.49 ± 1.61	11.36 ± 1.11	14.34 ± 1.35	-	-	11.76 ± 1.07
	The velocity of the foot (m/s) – Target middle distance, large height			**The velocity of the foot (m/s) – Air middle distance, large height**		
Number of mean results	-	1	2	-	1	1
Number of participants	-	9	15	-	7	7
Roundhouse kick (Mean, SD)	-	11.3 ± 0.8	13.79 ± 1.45	-	13.95 ± 4.16	16.29 ± 2.16
	The velocity of the knee (m/s) – Target middle distance, middle height			**The velocity of the knee (m/s) – Air middle distance, middle height**		
Number of mean results	-	-	8	-	-	2
Number of participants	-	-	99	-	-	30
Roundhouse kick (Mean, SD)	-	-	6.73 ± 0.56	-	-	5.99 ± 0.54
	The velocity of the knee (m/s) – Target middle distance, large height			**The velocity of the knee (m/s) – Air middle distance, large height**		
Number of mean results	-	-	-	-	1	1
Number of participants	-	-	-	-	7	7
Roundhouse kick (Mean, SD)	-	-	-	-	6.91 ± 1.78	7.96 ± 1.78
	The velocity of the hip (m/s) – Target middle distance, middle height			**The velocity of the hip (m/s) – Air middle distance, middle height**		
Number of mean results	-	-	7	-	-	2

Number of participants	-	-	93	-	-	30
Roundhouse kick (Mean, SD)	-	-	2.36 ± 0.31	-	-	2.04 ± 0.11
	The velocity of the knee (m/s) – Target middle distance, large height			**The velocity of the knee (m/s) – Air middle distance, large height**		
Number of mean results	-	-	-	-	1	1
Number of participants	-	-	-	-	7	7
Roundhouse kick (Mean, SD)	-	-	-	-	2.75 ± 0.77	2.83 ± 0.03
	Angular velocity of the knee flexion (°/s) Target			**Angular velocity of the knee flexion (°/s) Air**		
Number of mean results	1	1	5	-	2	2
Number of participants	15	6	45	-	13	13
Roundhouse kick (Mean, SD)	959 ± 302	837 ± 140	893 ± 194	-	534 ± 126	956 ± 92
	Angular velocity of the knee extension (°/s) – Target			**Angular velocity of the knee extension (°/s) – Air**		
Number of mean results	-	2	6	-	2	2
Number of participants	-	11	51	-	13	13
Roundhouse kick (Mean, SD)	-	1057 ± 130	1516 ± 181	-	1075 ± 186	1517 ± 107
	Angular velocity of the hip flexion (°/s) Target			**Angular velocity of the hip flexion (°/s) Air**		
Number of mean results	1	2	8	-	2	2
Number of participants	15	11	69	-	13	13
Roundhouse kick (Mean, SD)	496 ± 130	276 ± 46	334 ± 110	-	334 ± 31	442 ± 107
	Angular velocity of the hip extension (°/s) Target			**Angular velocity of the hip extension (°/s) Air**		
Number of mean results	-	1	7	-	2	2
Number of participants	-	6	86	-	13	13
Roundhouse kick (Mean, SD)	-	419 ± 99	297 ± 110	-	154 ± 71	325 ± 141
	Total execution time (s) – Target middle distance, middle height			**Total execution time (s) – Air middle distance, middle height**		
Number of mean results	1	2	1	-	-	1
Number of participants	11	43	12	-	-	7
Roundhouse kick (Mean, SD)	1.06 ± 0.17	0.955 ± 0.115	0.840 ± 0.012	-	-	0.848 ± 0.110
	First phase execution time (s) – Target middle distance, middle height			**First phase execution time (s) – Air middle distance, middle height**		

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Number of mean results	-	-	2	-	1	2
Number of participants	-	-	12	-	7	13
Roundhouse kick (Mean, SD)	-	-	0.255 ± 0.143	-	0.320 ± 0.56	0.171 ± 0.201
	Second phase execution time (s) – Target middle distance, middle height			**Second phase execution time (s) – Air middle distance, middle height**		
Number of mean results	-	-	2	-	1	2
Number of participants	-	-	12	-	7	13
Roundhouse kick (Mean, SD)	-	-	0.113 ± 0.077	-	0.200 ± 0.048	0.146 ± 0.019
	Execution time to hit the target (s) middle distance, middle height			**Execution time to hit the target (s) large distance, middle height**		
Number of mean results	2	3	7	2	3	4
Number of participants	42	65	87	42	65	53
Roundhouse kick (Mean, SD)	0.297 ± 0.073	0.296 ± 0.048	0.280 ± 0.099	0.358 ± 0.047	0.368 ± 0.084	0.316 ± 0.059

Forest Plots of the Front and Roundhouse Kick

The graphical presentations of the pooled data are shown in the forest plots, separately for the FK and RK (Figure 2(a–f), Figure 3(a–d)). The normalized weighted mean with 95% CI of the impact force was visually compared to show the differences among the levels of groups (novice, sub-elite, and elite) that executed both the FK and RK, where in addition, these differences were in various distances from the solid target. Unfortunately, comparing the maximum forces of the FK was impossible due to the lack of studies with novice and sub-elite participants, and for the RK, maximum force was not mentioned in any studies. Comparing impact force between the FK and the RK shows that the impact force of the FK was higher than the RK (Figure 2(d), Figure 3(a)).

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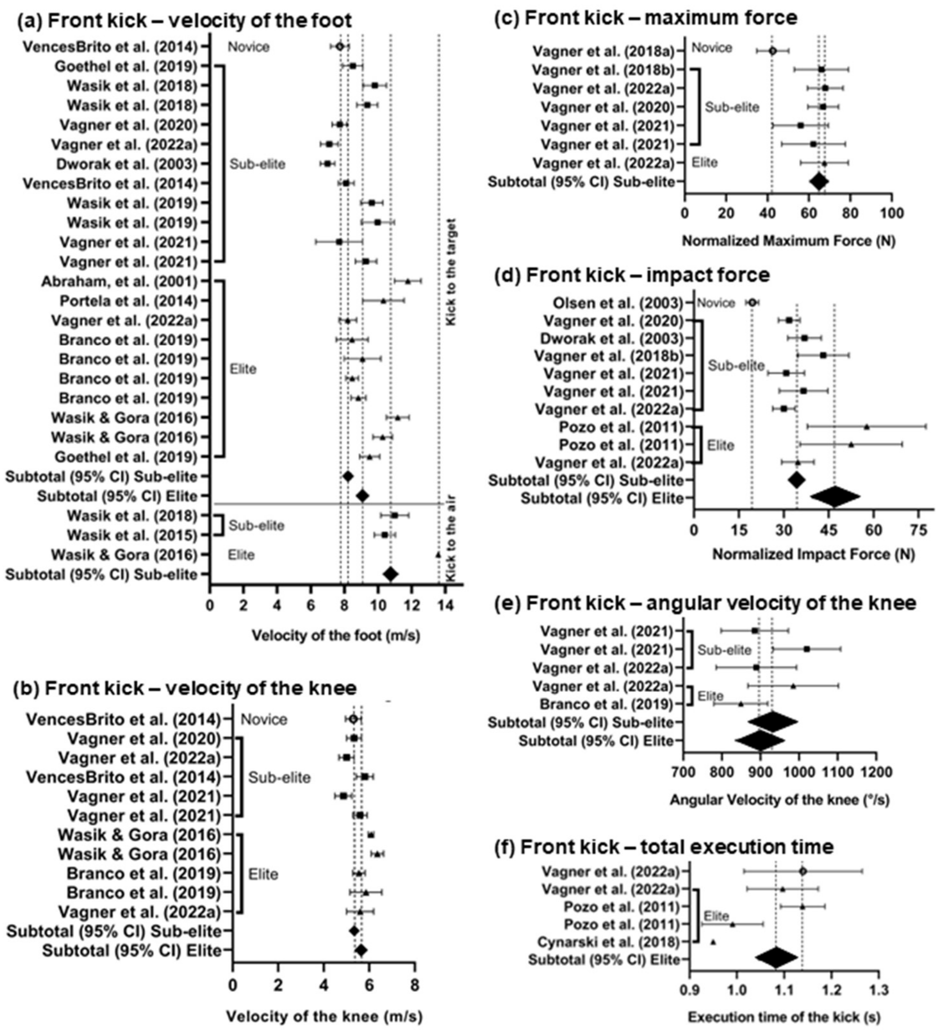

Figure 2. Forest plots presenting the mean and 95% confidence interval: (a) The front kick maximum velocity of the foot; (b) The front kick maximum velocity of the knee; (c) The front kick maximum force; (d) The front kick impact force; (e) The front kick maximum angular velocity of the knee; (f) The front kick total execution time. Note: ○ – novice, ■ – sub-elite, ▲ – elite, and ♦ – presents weighted mean by the number of participants and their 95% CIs. References: [1–3,7,11,15–17,24,34–42].

Visually comparing the weighted mean with 95% CI of the maximum foot velocity executed from the middle distance into the solid target placed at middle height showed slight differences between the sub-elite and elite groups for the FK (Figure 2(a)) and RK (Figure 3(c)). However, comparing the maximum foot velocity between the sub-elite and novice groups was impossible due to the lack of studies. When comparing the maximum foot velocity between the FK and RK, it is evident that the velocity of the RK was higher than the FK.

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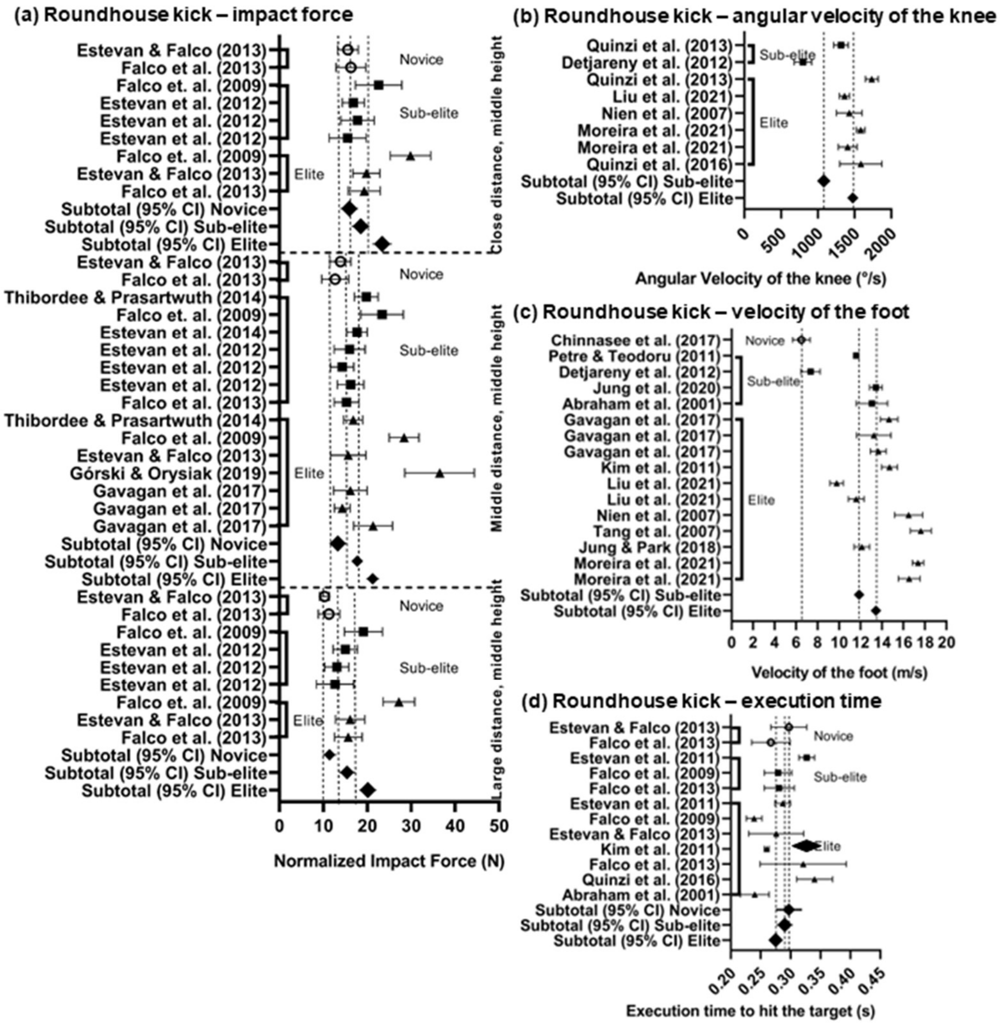

Figure 3. Forest plots presenting the mean and 95% confidence interval: (a) The roundhouse kick impact force; (b) The roundhouse kick maximum angular velocity of the knee; (c) The roundhouse kick maximum velocity of the foot; (d) The roundhouse kick execution time. Note: ○ – novice, ■ – sub-elite, ▲ – elite, and ♦ – presents weighted mean by the number of participants and their 95% CIs. References: [12–14,18,22,23,28,40,43–57].

Comparing the maximum angular velocity of the knee extension was possible only between sub-elite and elite groups that executed the kick from a middle distance into the solid target placed at middle height (Figure 2(e), Figure 3(b)). Comparing the maximum angular velocity of the knee extension between the FK and RK was RK faster than the FK.

Regarding the execution time, it could be calculated only at the elite group executed the FK into the solid target (Figure 2(f)) and at groups' levels in the execution of the first and second phase RK (from start to the hit into the target) from middle distance into the solid target placed at middle height (Figure 3(d)). In other cases, either comparison was not possible due to the lack of studies, or it was evident that there were no differences.

Comparing the Kicks' Dynamic Forces and Kinematic Indicators

There was enough data to compare impact force, the maximum velocity of the foot, knee, and hip, as well as the maximum angular velocity of the knee extension, where the conditions for kick execution were set up at the middle distance from the solid target, which was placed at the middle height.

Impact Forces of the Kick

There were differences in the normalized weighted mean of the impact force among novice, sub-elite, and elite groups within the FK and RK, as shown in Figure 4(a), $F_{5, 363} = 84.15$, p = .00001, $\mu^2 = 0.54$, where the post hoc tests revealed that the impact force of the FK was higher than the RK between the novice, sub-elite, and elite groups ($p < 0.01$, $d = 1.95$; $p < 0.01$, $d = 1.97$, and $p < 0.01$, $d = 1.71$, respectively). Regarding differences in experience levels within the front kick, the elite group had higher impact force than the sub-elite and novice groups ($p < .01$, $d = 0.8$ and $p < 0.01$, $d = 1.87$, respectively), and the sub-elite group had a higher impact force than novice group ($p < 0.01$, $d = 1.85$). Within the RK, the difference was between the elite and novice groups ($p < 0.01$, $d = 1.3$).

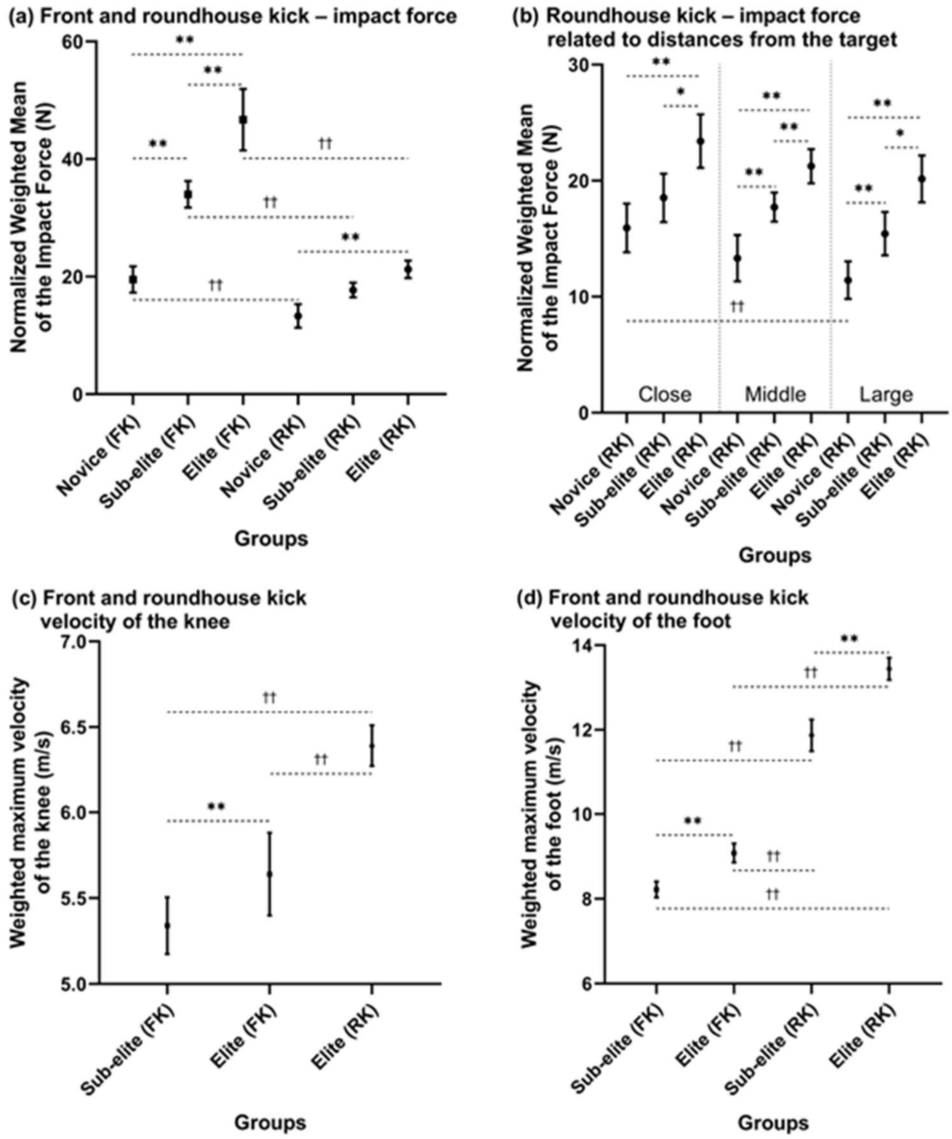

Figure 4. Differences among groups and distances from the target: (a) The front and roundhouse kick - impact force; (b) The roundhouse kick - impact force related to distances from the target; (c) The front and roundhouse kick - velocity of the knee; (d) The front and roundhouse kick - velocity of the foot. Note: FK – front kick; RK – roundhouse kick; *Significant differences among groups, $p < 0.05$; **Significant differences among groups, $p < 0.01$; ††Significant differences between the front and roundhouse kick or distances from the target, $p < 0.01$; Vertical bars denote 95% CIs.

In terms of the distances from the target within the RK, there were differences in the normalized weighted mean of the impact force among the close, middle, and large distances for all experience levels (Figure 4(b), $F_{8, 472} = 15.517$, p = 0.00001, $\mu^2 = 0.21$). Post hoc tests revealed that the elite group

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had higher impact force than the sub-elite and novice groups within the close distance ($p < 0.05$, d = 0.66 and $p < 0.01$, d = 1.08, respectively), within the middle distance ($p < 0.01$, d = 0.57 and $p < 0.01$, d = 1.23, respectively), and within the large distance ($p < 0.05$, d = 0.73 and $p < 0.01$, d = 1.51, respectively). The sub-elite group had a higher impact force than the novice group within the middle and large distance ($p < 0.01$, d = 0.68 and $p < 0.01$, d = 0.66, respectively), and the novice group had a higher impact force within the close distance than within the large distance ($p < 0.01$, d = 0.4).

The Velocity of the Knee and Hip

There were differences in the weighted mean of the maximum knee velocity between the sub-elite and elite groups within the FK and the RK, as shown in Figure 4(c) ($F_{2,210}$ = 52.05, p = .0001, μ^2 = 0.33), where the post hoc tests revealed that the elite group had higher maximum knee velocity within the roundhouse kick into the target than the sub-elite group and elite group ($p < 0.01$, d = 1.64 and $p <$ 0.01, d = 1.04, respectively). However, including the novice group and sub-elite group within the RK was impossible due to the lack of studies. Concerning the weighted mean of the maximum hip velocity, there were no differences between the elite and sub-elite groups within the FK and the elite group within the RK. The comparison of the knee and hip maximum velocity between the execution of the FK or RK into the solid target and the air was impossible due to the lack of studies.

The Velocity of the Foot

There were differences in the weighted mean of the foot maximum velocity between the sub-elite and elite groups within the FK and RK, as shown in Figure 4(d) ($F_{3, 369}$ = 439.7, p = 0.00001, μ^2 = 0.78), where the post hoc tests revealed that the elite group had higher foot maximum velocity than the sub-elite group within the RK ($p < 0.01$, d = 1.24). The elite group within the RK had higher foot maximum velocity than the elite and sub-elite groups within the FK ($p < 0.01$, d = 3.4; and $p < 0.01$, d = 4.21 respectively). The sub-elite group within the RK had higher foot maximum velocity than the elite and sub-elite groups within the FK ($p < 0.01$, d = 2.52; and $p < 0.01$, d = 3.43 respectively). In addition, there were differences in the weighted mean of the foot velocity within the FK, where the elite group had a higher maximum foot velocity than the sub-elite group ($p < 0.01$, d = 0.77).

Regarding the weighted mean of the maximum foot velocity between the execution kick into the solid target and the air, the maximum foot velocity of the FK into the air was higher than the kick into the solid target in the sub-elite group ($p < 0.01$, d = 2.42, Figure 5(a)) and the maximum foot velocity of the RK into the solid target was higher than kick into the air in the elite group ($p < 0.01$, d = 1.36, Figure 5(a)). The comparison of other groups was impossible due to the lack of studies.

Angular Velocity of the Knee and Hip

There were differences in the weighted mean maximum angular velocity of the knee extension between the sub-elite and elite groups, as shown in Figure 5(b) ($F_{3, 122}$ = 108.113, p = 0.00001, μ^2 = 0.73), where the post hoc test revealed that the elite group had a higher maximum angular velocity than the sub-elite group within the RK ($p < 0.01$, d = 2.6) and than the sub-elite and elite groups within the FK ($p < 0.01$, d = 3.39; $p < 0.01$, d = 3.26, respectively). The sub-elite group had a higher maximum angular velocity within the RK than the sub-elite and elite group within the FK ($p < 0.01$, d = 1.08; $p <$ 0.01, d = 1.16, respectively). However, there was not enough data for comparison with the novice group.

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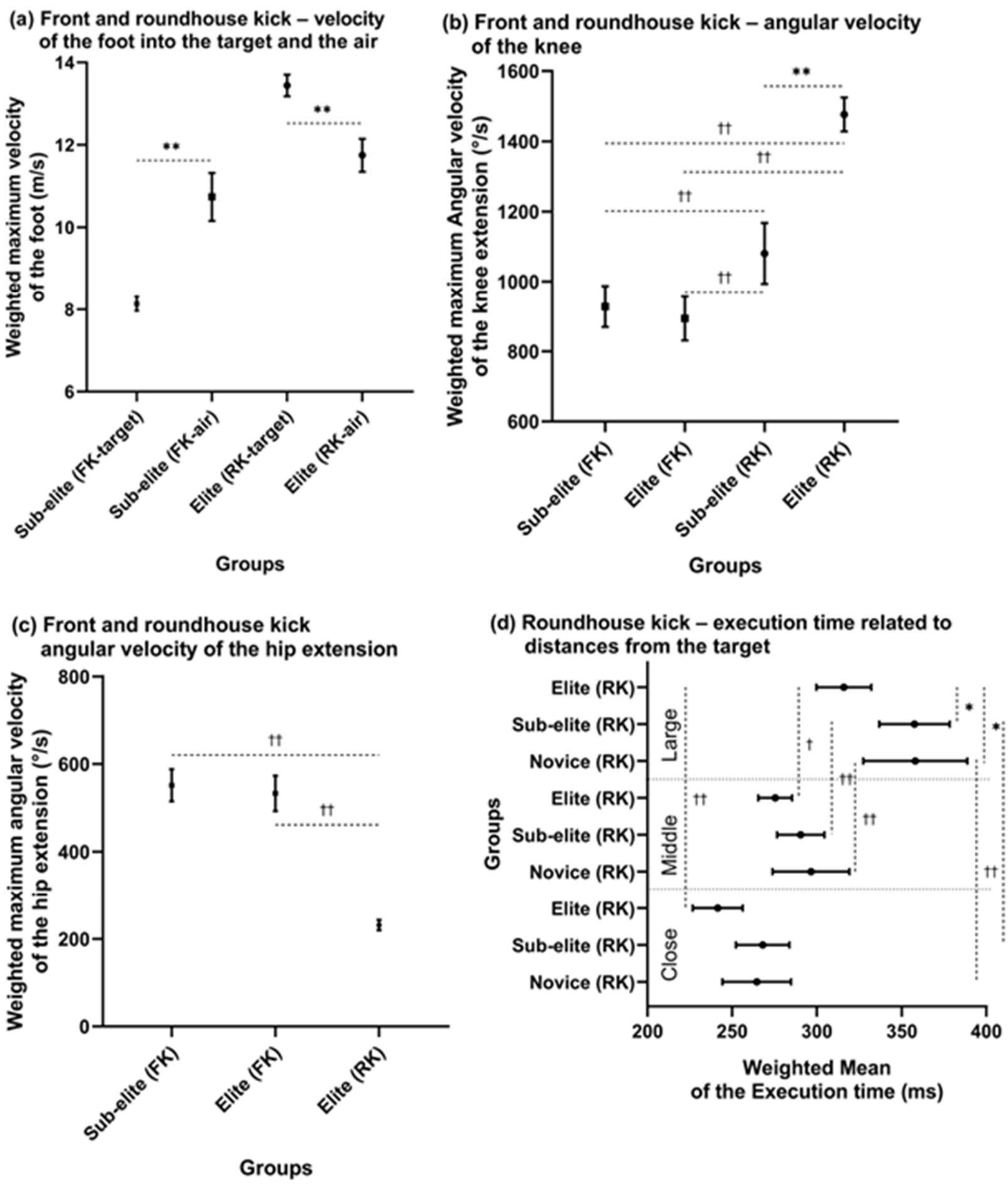

Figure 5. Differences among groups and distances from the target: (a) The front and roundhouse kick - velocity of the foot; (b) The front and roundhouse kick - angular velocity of the knee extension; (c) The front and roundhouse kick angular velocity of the hip extension; (d) The roundhouse kick execution time related to distance from the target. Note: FK – front kick; RK – roundhouse kick; Close, Middle, and Large denotes the distance from the target; *Significant differences among groups, $p < 0.05$; **Significant differences among groups, $p < 0.01$; †Significant differences between the distances within one group, $p < 0.05$; ††Significant differences between the front and roundhouse kick or distances from the target, $p < 0.01$; Vertical or horizontal bars denote 95% CIs.

Regarding the maximum angular velocity of the hip extension, there were differences between the FK and RK into the solid target placed at a middle height. The elite group within the RK had lower maximum angular velocity than the sub-elite and elite groups within the FK, as shown in Figure 5(c) ($p < 0.01$, $d = 4.14$ and $p < 0.01$, $d = 4.35$, respectively,). However, including the novice group in the comparison was impossible due to the lack of studies. There were no differences between the sub-elite and elite groups within the FK.

Execution Time

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Comparison of execution time among groups related to the participants′ experience and distance from the target was possible for the first and second phases together (from start to contact with the target) within the RK. There were differences in the weighted mean of the execution time among the close, medium, and large distances within the novice, sub-elite and elite groups, as shown in Figure 5(d) ($F_{8, 505}$ = 20.432, p = 0.00001, μ^2 = 0.24). Post hoc tests revealed that the elite group had lower execution time than sub-elite and novice groups within the large distance from the target ($p < 0.05$, d = 0.58 and $p < 0.05$, d = 0.52, respectively).

Regarding the differences within individuals groups, the novice group had a higher execution time within the large distance than at the close distance ($p < .01$, d = 0.71), the sub-elite group had a higher execution time within the large distance than middle and close distances ($p < 0.01$, d = 0.94 and $p < 0.01$, d = 1.2, respectively), and the elite group had higher execution time within the large distance than middle and close distances ($p < 0.01$, d = 0.76 and $p < 0.01$, d = 1.32, respectively). Comparing the execution time of the FK was impossible due to the lack of studies.

Regarding the comparison between the target type, the first and second phase of the RK at the elite group was shorter within the execution of the kick into the target than into the air. However, the execution time was not significantly different in both phases of the kick (p = 0.210 and p = 0.213).

4. Discussion

The review identified significant differences between FK and RK in terms of impact forces and velocity in the different target types. The main findings of this review supported the hypothesis that the impact forces of the FK were higher than the RK for all skill levels (novice, sub-elite, and elite) when kicking from the middle distance to a solid target placed at middle height. Specifically, the impact forces of the FK were 47% higher in the novice group, 92% higher in the sub-elite group, and 120% higher in the elite group compared to the RK. Additionally, the maximum foot velocity of the RK was faster than the FK for the sub-elite and elite groups, with a 44% increase in velocity for the sub-elite group and a 48% increase for the elite group.

Further analysis of the maximum foot velocity within the FK revealed interesting differences between the sub-elite and elite groups. The sub-elite group exhibited a 32% higher maximum foot velocity when kicking into the air compared to kicking into a solid target. In contrast, the elite group had a 14% higher maximum foot velocity when kicking into a solid target compared to kicking into the air within the RK.

When examining the maximum angular velocity of knee extension, the elite group showed a 37% higher maximum angular velocity compared to the sub-elite group within the RK. Moreover, the elite group exhibited a higher maximum angular velocity of knee extension by 65% within the FK compared to the RK under the same conditions.

It is worth noting that the review identified several gaps in the existing literature. For example, there was a lack of studies comparing the maximum forces of FK and RK, particularly among novice and sub-elite participants. Additionally, the review highlighted the need for more research on execution time and maximum angular velocity of the hip extension in both kicks. Addressing these gaps would provide a more comprehensive understanding of the biomechanical characteristics of FK and RK.

The Impact Force of the Kicks

The impact force of kicks was examined in this section. The comparison was made at a middle distance from the target placed at the middle height for the FK and at different distances for the RK. In the elite group, the normalized weighted mean of impact forces within the FK was 38% higher compared to the sub-elite group and 140% higher compared to the novice group (with only one selected study available for novices). Similarly, in the RK at the middle distance from the solid target, the normalized weighted mean of impact force in the elite group was 20% higher than the sub-elite group and 60% higher than the novice group (Figure 4(a)). Moreover, for the RK, the impact forces decreased as the distance from the solid target increased, observed across all participant levels (close, middle, and large distances) (Figure 4(b)).

From a close distance, the novice, sub-elite, and elite groups exhibited higher impact forces by 20%, 5%, and 20%, respectively, compared to a middle distance. Furthermore, they displayed higher impact forces by 39%, 10%, and 16%, respectively, compared to a large distance. However, the only significant difference was observed between the close and large distance in the novice group. This finding is consistent with a study [14] where no significant differences in impact force were found concerning execution distance in expert competitors.

Contrary to the expectation of a higher impact force with more extended time for action, the impact force decreased as the distance from the target increased. This finding is likely attributed to the stance position adopted by fighters when executing the RK from a long distance, which differs from the stance position when closer to the target. This supports the notion that within kicking from a long distance, the standing position is similar to a 90° stance position, limiting the RK's effectiveness [44].

The impact force of the kick may be related to the isokinetic strength of the hip flexors and extensors and the knee angular velocity [2,49]. Therefore, the fighters should focus on enhancing the impact force from a larger distance with the help of increasing their angular velocity during knee extension in the pre-contact phase [10].

When comparing the normalized weighted mean of impact force between the FK and RK, it was observed that in the middle distance from the target, the FK had a higher impact force than the RK by 47% in the novice group, 92% in the sub-elite group, and 120% in the elite group.

The Maximum Velocity of the Kicks

The maximum velocity of kicks was examined in various studies, which presented different conditions for kick execution, including target type, target height, distance from the target, stance position, and participant level. However, enough studies to compare were only for foot velocity executed into a solid target and in the air. The variations in conditions for kick execution across studies, such as target type, target height, and stance position, make it challenging to draw definitive conclusions.

When comparing the weighted mean of maximum foot velocity between the FK and RK, it was found that the RK exhibited higher velocities than the FK at the middle distance from the target. Specifically, the RK was 44% higher in the sub-elite group and 48% higher in the elite group. Moreover, the weighted mean of maximum foot velocity within the FK into the solid target was 11% higher in the elite group compared to the sub-elite group (Figure 4(d)). In this review, the maximum foot velocity range in the front kick varied from 7 to 9.98 m/s in the sub-elite group, from 8.2 to 10.32 m/s in the elite group, and 7.7 m/s in the novice group. Additionally, the weighted mean of maximum foot velocity within the RK executed into the solid target at the middle distance was 13.3% higher in the elite group compared to the sub-elite group (Figure 4(d)).

In terms of comparing the execution of the FK into the solid target or the air, it was consistent with study [58] that the FK into the air demonstrated higher foot velocities than into the target (Figure 5(a)). The weighted mean maximum foot velocity of the FK into the air in the sub-elite group was 31% higher compared to the foot velocity into the target. Conversely, for the RK in the elite group, the foot velocity in execution into the solid target was 14% higher than into the air (Figure 5(a)).

Regarding the maximum velocity of the knee in the FK and RK, the elite group exhibited a 6% higher maximum velocity of the knee within the FK compared to the sub-elite group. Furthermore, the elite group had a 13% and 20% higher maximum velocity of the knee within the RK compared to the sub-elite and novice groups within the FK, respectively (Figure 4(c)). Unfortunately, due to different conditions of kick execution, such as varying distances and heights of the target, further comparison of hip and knee velocity between the groups was impossible due to a lack of available data.

While exploring the data from selected articles, it was also found that to improve the maximum foot velocity in the execution of the FK, athletes need to increase the velocity of the knee traveling toward the target [7,36,58]. Investigating the optimal kicking techniques, such as the positioning of

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the supporting leg, the angle of hip and knee flexion, and the coordination of joint movements, can contribute to a deeper understanding of how athletes can generate higher foot velocities.

Angular Velocity of the Kicks

The comparison of angular velocities between sub-elite and elite groups revealed significant differences only within the RK. The elite group had a 37% higher maximum angular velocity of knee extension compared to the sub-elite group when executing the RK towards the target at a middle height (Figure 5(b)). Additionally, a notable disparity was observed between the FK and RK, with the elite group demonstrating a 65% higher maximum angular velocity of knee extension in the RK compared to the FK. Conversely, within the FK, the elite group exhibited a 138% higher maximum angular velocity of hip extension compared to the RK (Figure 5(c)). When examining differences within the RK, it was observed that the elite group achieved a 39% higher maximum angular velocity of hip extension when executing kicks into the air compared to the target. Unfortunately, there are not enough studies to compare maximum angular velocities for knee and hip flexion within the RK and FK, specifically within the sub-elite group.

In the context of other studies, it was found that the maximum angular velocity of knee extension can be influenced by agonist and antagonist activity [59]. For example, the elite group exhibited clear antagonist activation of the biceps femoris during the extension phase of the FK, whereas such activation was not evident in the amateur group [30]. The elite group also achieved higher maximum angular velocities of the hip and knee compared to the amateur group. However, it should be noted that the antagonist activity in the biceps femoris toward the end of the analyzed time interval does not significantly affect the hip joint moment during the FK [60]. These findings partially explain the results where an increase in angular velocity of knee extension was observed after eight weeks of training focused on explosive lower limb strength without a significant increase in hip angular velocity [2]. Nevertheless, the primary movement of the hip is cited as crucial for the overall effectiveness of both FK and RK [10,49].

Analyzing the contributions of individual muscles and their coordination within the lower limb complex can provide valuable insights into optimizing angular velocities and improving kick performance.

Execution Time of the Kicks

The execution time of a kick is typically divided into three phases: the pre-phase, the attack phase, and the return phase.[7] The first two phases, known as the kicking time, were compared within the RK due to the selected articles in this systematic review. The findings revealed that the elite group had shorter kicking times compared to the sub-elite and novice groups across different distances. Specifically, the elite group had a 5% shorter kicking time at close distance, 10% shorter in middle distance, and 12% shorter at large distance compared to the sub-elite group. Similarly, compared to the novice group, the elite group had a 7% shorter kicking time at close distance, 9% shorter at middle distance, and 12% shorter at large distance (Figure 5(d)). Notably, the greatest differences in kicking time were observed within each group at different distances, with significant reductions in kicking time from close to the middle and from close to large distances. The elite group exhibited the highest differences between close and middle distances.

The total time of the kick is primarily influenced by technique, as elite athletes demonstrate faster hip flexion, knee flexion, and extension compared to non-elite athletes [54,61]. Therefore, to achieve shorter kick times, it is advisable to focus primarily on knee velocity in the FK [36,58], and the angular velocity of knee extension in the RK [18].

Limitations of the Study

Despite the valuable insights provided by the systematic review on kick biomechanics, there are certain limitations that should be acknowledged. The review may have excluded relevant studies due to specific inclusion criteria, such as language restrictions or different name FK or RK. This could introduce a potential bias and limit the generalizability of the findings. The included studies may have used different methodologies, sample sizes, and participant characteristics, making it challenging to directly compare and synthesize the results. The heterogeneity of the studies could impact the overall conclusions and limit the ability to draw firm conclusions. The lack of standardized measurement protocols and different measurement tools for measuring and analyzing kick biomechanics across studies may introduce variability in the data collection and analysis methods. This could affect the consistency and reliability of the results. The studies included in the review may have focused on specific populations, such as trained athletes or individuals of a specific age group. Therefore, the findings may not be applicable to other people, such as older adults, or individuals with specific physical conditions. The review predominantly included cross-sectional studies, which provide a snapshot of kick biomechanics at a specific point in time. The review focused on front kicks and roundhouse kicks, but there are various other types of kicks used in combat sports and martial arts. The exclusion of different kick types limits the generalizability of the findings to a broader range of kicking techniques.

Addressing these limitations and conducting research with more rigorous methodologies, larger sample sizes, standardized protocols, and diverse populations will enhance the understanding of kick biomechanics and provide more robust evidence for training and performance optimization.

5. Conclusions

The systematic review revealed several important findings regarding FK and RK. Firstly, the FK demonstrated a higher impact force compared to the RK across all experience groups, indicating its potential effectiveness in generating forceful strikes. On the other hand, the RK had a higher maximum foot velocity, suggesting its potential for swift and rapid execution.

Furthermore, differences were observed between the FK and RK when executed into the target or into the air. Specifically, the FK demonstrated a higher maximum velocity when executed in the air. Conversely, the RK showed a higher maximum velocity when executed into the target.

In terms of maximum angular velocity, the RK displayed a higher maximum angular velocity of the knee extension within the elite group. This highlights the importance of knee movement and extension in generating speed and power during the RK. However, it is worth noting that the FK exhibited a higher maximum angular velocity of the hip extension compared to the RK within the same elite group, indicating the significance of hip movement in executing the FK with speed and efficiency.

In summary, this systematic review provides valuable insights into the differences between the FK and RK in terms of impact force, maximum velocity, and maximum angular velocity. These findings contribute to a better understanding of the biomechanical aspects, practical use, and potential advantages of each kick.

Supplementary Materials: Figure S1: Assessment of methodological quality and risk of bias; Table S1: The search terms used in the review to identify dynamics forces and kinematic indicators of the front and roundhouse kick; Table S2: Summary of studies.

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