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Determining the Prognostic Validity of the Unilateral Horizontal Cyclic Jumps Test in Sprint Performance

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Abstract: In sports practice, motor tests are commonly used to predict success in specific segments of sprint running, as well as post-injury tests in rehabilitation. The purpose of this analytical cross-sectional study was to determine the prognostic validity of the unilateral horizontal cyclic jumps for a 20 m (UHCJ20m) test on sprint running success. A sample of 118 kinesiology students aged 20.5 ± 1.2 years with an average height of 179.7 ± 6.4 cm and a body mass of 75.6 ± 7.3 kg was used to determine the correlation between the results of the UHCJ20m test and the results of the 20 m sprint start run (MRLS20m), the 20 m sprint flying start run (MRFS20m), and the 100 m run (M100m). The results showed a moderate correlation in all tests (MRLS20m (R = 0.49), MRFS20m (R = 0.53), and M100m (R = 0.38)) with UHCJ20m. In addition to the final result, the multiple regression analysis showed a significant moderate correlation between the kinematic parameters of the UHCJ20m test and the results in the MRLS20m (R = 0.38), MRFS20m (R = 0.49), and M100m (R = 0.37) tests. The stride length (SL) and the contact time (CT) of the UHCJ20m test were statistically significant predictors for the 100 m sprint, the number of steps for MRLS20m, and the SL and the CT for MRFS20m sprint success. Unilateral horizontal cyclic jumps are a significant predictor of success in sprint running, especially for the maximal speed running segment.

Keywords: sport; performance enhancement; strength and power; start acceleration; maximal speed

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Citation: Babić, V.; Milinović, I.; Čule, M.; Dolenec, A. Determining the Prognostic Validity of the Unilateral Horizontal Cyclic Jumps Test in Sprint Performance. *Appl. Sci.* **2021**, *11*, 7038. https://doi.org/10.3390/app11157038

Academic Editor: Mark King

Received: 5 July 2021
Accepted: 27 July 2021
Published: 30 July 2021

1. Introduction

Various test batteries and measurements of certain morphological, motor, functional, psychological, and other characteristics are used in different periods of sports practice to enable the best possible selection of candidates for a particular sport or sports discipline, as well as to monitor and evaluate the training process. The interest related to sprinting focuses on morpho-anthropological measurement on the relationship between certain dimensions and success in sprinting [1–4]. There are many available research studies investigating the relationship between performance in various motor tests, especially those measuring speed, explosive strength, and power [5–12], and success in sprint running. Jumps are among the tests commonly used to predict specific sprint running phases. The most commonly used tests in assessing sprinters, selecting them and monitoring their training process are bilateral and unilateral horizontal and vertical jumps. The research topic of many authors [13–17] has been the relationship between the results of the jumps' tests and certain segments of sprint running, not exclusively related to track and field but also to all sports in which the aforementioned sprint structures dominate (soccer, football, rugby, basketball, etc.). A relatively large number of research studies examined bilateral vertical jumps and their relationship to sprint running results [5–7,14]. The most commonly used tests of lower extremity explosive strength are the squat jump (SJ), the countermovement jump (CMJ), the standing long jump (SLJ), and others. Cronin and Hansen [14] used the SJ and the CMJ, among other tests, to assess lower extremity limb explosive strength in a group of New Zealand rugby players and its relationship to running speed at 5 m, 10 m, and 30 m. The height of both jumps and their relative power output showed a statistically significant correlation with three measures of speed (r= −0.43 to −0.66). Moreover, the height of both jumps and their relative power output were significantly greater in faster players. A group of authors [18] investigated the relationship between the CMJ and the 5 m sprint in trained athletes and made a similar conclusion about a relatively high relationship between the CMJ on the Smith's machine and the 5 m sprint (r= −0.66 to −0.80). Research studies whose aim was to establish a relationship between lower extremity explosive strength and sprinting have often been conducted using different versions of bilateral vertical jumps [19–22]. It was found that acyclic movements (SJ, CMJ, and other vertical jumps) can be used to predict cyclic movements (sprint) [5], which could explain the moderate correlation between acyclic and cyclic tasks [17,21,23]. Agar-Newman and Klimstra [24] conducted a study with Canadian female rugby players to determine the relationship between the SLJ and the standing triple jump (STJ) and sprinting at 10 m and 40 m (r = 0.51 to 0.75). The results obtained suggest that the horizontal jump test can be used as a valuable tool to determine sprinting ability in elite female rugby players. The STJ test showed greater predictive ability than the SLJ test for the maximum running speed and acceleration phase. Maulder and Cronin [5] made similar conclusions by examining the relationship between tests of vertical (SJ, CMJ, and repetitive (cyclic) squat jumps) and horizontal jumps (horizontal SJ, horizontal CMJ, and horizontal repetitive (cyclic) jumps) and the 20 m sprint test. Their study was conducted on 18 athletes from different sports dominated by the lower extremities. Although all jump types showed a high correlation with the running speed test, the horizontal repetitive (cyclic) jump test proved to be the best predictor of the 20 m sprint outcome (r = −0.86). In the study by Lockie at al. [25], the horizontal unilateral jump test (USLJ) showed the highest correlation with the 30 m sprint run in soccer players; r = −0.65 to r = −0.90. Maćkala, Fostiak, and Kowalski [11] investigated the correlation between horizontal jumps (SLJ, five jumps from standing (S5J), ten jumps from standing (S10J)) and kinematic parameters and sprinting times on specific segments of 100 m (10 m, 30 m, and 100 m) using competitive sprinters and student athletes. The study results showed a high correlation between all three tests and the 10 m sprint run (start and start acceleration), the 30 m sprint run (acceleration), and the 100 m sprint run (maximum running speed). The correlation coefficients ranged from r = −0.66 to r = −0.88, but, as the authors noted, these correlations were characteristic only of the sprinter group, not the student-athlete group.

Available research studies lack data on unilateral cyclic horizontal jumps measured in units of time, with the exception of the studies by Dolenec et al. [26], Babić [27], and Kise et al. [28] in rehabilitation after the knee injury. Using a large sample of girls, Babić [27] tested differences between gifted and less gifted girls in the 60 m sprint running. Among other tests, Babić used the test of 30 m unilateral horizontal cyclic jumps (UHCJ30m). The time and number of jumps along the 30 m distance using the left and right leg contribute to the discrimination of gifted and less gifted girls in the 60 m sprint running. The author stated that the UHCJ30m test should be adapted for this age group considering the psychophysical characteristics of children of this age and that the test distance should be shortened. The UHCJ30m test is similar to the UHCJ20m test validated by Dolenec et al. [26] in their research study of student athletes. The authors [26] state how the composite measuring instrument (UHCJ20m) has a high reliability (Cronbach α = 0.95, ICC = 0.94), a high homogeneity (AVR = 0.88), and they state how the test has satisfactory sensitivity.

Horizontal jumps showed greater correlation than vertical jumps with specific segments of sprint running [6–12]. However, some research studies found a correlation between certain kinematic parameters of the vertical jumps CMJ and SJ (power and force) with start and start acceleration (10 m sprint), whereas horizontal jumps showed no statistically significant correlation [29]. The UHCJ20m test is used in sports practice but has not been standardized and validated. To date, there has been no such research, so there was a need for such research to determine the legitimacy of its use in practice and to gain insight into the kinematic parameters of the test and their effects on sprint running performance.

The purpose of this research study was to determine the relationship between unilateral horizontal jumps and running speed (sprinting). The aim of this research study was to investigate correlations between kinematic parameters of unilateral horizontal jumps and 20 m running test results from a block start and a flying start, i.e., the start acceleration, the maximum running speed, and the 100 m running result. The hypothesis of this research study was that the UHCJ20m test has a significant correlation with the M100m, MRLS20m, and MRFS20m tests and that a significant correlation exists between some kinematic parameters of the UHCJ20m test with the M100m, MRLS20m, and MRFS20m test results.

2. Materials and Methods

2.1. Subject Sample

The sample consisted of 118 male subjects with a mean age of 20.5 ± 1.2 years, a mean height of 179.7 ± 6.4 cm, and a mean body mass of 75.6 ± 7.3 kg. The subjects were positively selected for the sport considering motor knowledge and health status; they came from different sports (martial arts, basketball, handball, soccer, volleyball, gymnastic, swimming, hockey, ice skating, dancing, etc.) and did not belong to the population of sprinters. All subjects had at least 20 h of athletic training and learned specific sprinting sections (i.e., start, start acceleration, sprinting technique, different types of horizontal and vertical jumps, ABC of basic athletic drills, etc.). Convenience sampling was used in this research study. Only the subjects who met the predefined criterion regarding the correct performance of the UHCJ20m test (average contact time ≤ 250 ms) were selected for the subject sample.

The study was conducted in accordance with the guidelines of the Declaration of Helsinki and approved by the Ethics Committee of the Faculty of Kinesiology, University of Zagreb (No. 42/2018, 30 October 2018). Informed consent was obtained from all subjects involved in the study.

2.2. Variable Sample

The variable sample included three motor tests to assess running speed: 100 m running (M100m), 20 m running from a block start (MRLS20m), and 20 m running from a flying start (MRFS20m). The unilateral horizontal 20 m cyclic jumps' test (UHCJ20m) [26] was used to assess lower extremity explosive strength.

In addition to the result in the UHCJ20m test, the following parameters were determined (time-related and kinematic): time (s), v—average movement speed (m/s), SL—average step length (m), SF—average step frequency (str/s), CT—average contact time (ms), FT—average flight time (ms), and SN—number of steps (n).

2.3. Instruments

2.3.1. Optojump Next

The Optojump Next system (Microgate, Bolzano, Italy) was used to measure the kinematic parameters in MRLS20m, MRFS20m, and UHCJ20m. The system consists of 40 bars (20 TX bars and 20 RX bars), each 1 m long. Each bar has 96 optical sensors with an infrared wavelength of 890 nm. The space resolution is 1.041 cm. The distance from the optical center of the sensor to the ground surface was three millimeters. The timing accuracy of the system was 1 millisecond. The Optojump Next software ran on a laptop computer.

2.3.2. Brower Timing System

Timing in MRLS20m, MRFS20m, and UHCJ20m was performed using a wireless photocell system (Brower Timing System, Draper, UT, USA). In MRLS20m and MRFS20m, one pair of photocells was positioned at each of a start and finish line. Each pair consisted of a transmitting unit (infrared light) and a receiving unit. The distance between the units was 2 m. In the case of UHCJ20m, only one pair of photocells was used at the finish line to stop the timing, while the start of the measurement was performed manually. Communication between the coach's monitor and the transmitting unit was via radio frequency (432.8 Hz). The accuracy of the timing was 1/1000 of a second.

2.4. Tests

2.4.1. Experimental Protocol

At the beginning of the testing session, the subjects, prepared with a warm-up, participated in a 20-min collective warm-up to prepare for the performance of the tasks, which consisted of running at variable speeds interspersed with various tasks, predominantly a series of ABC track and field exercises, horizontal jumps, and hops, followed by some stretching exercises. The first test performed was M100m. After two to three days, MRLS20m, MRFS20m, and UHCJ20m tests were performed on the same day. The rest between the tests as well as the trails was 15 min. Before the subjects performed the test, they were shown the test along with detailed instructions and a trial. MRLS20m was the first test that the subjects performed twice. Then, according to the protocols explained earlier, they performed MRFS20m and UHCJ20m tests with the dominant leg and repeated them twice as well.

2.4.2. 100 m Running

The test was performed on a track that complies with the track and field rules according to World Athletics. The measurement was carried out electronically over the 100 m distance, individually. The system for electronic measurement (consisting of a base—electronic measuring instrument, timer, and personal computer) had connections for a starting gun, an electronic start block Omega (records the time of the latent reaction of the examinee: from the shot or the signal for the start of the race to the reaction of the examinee—leaving the starting block), connections for 10 pairs of cable photocells, and a specially developed computer program "BRZ." The task was performed twice with a one-day break between measurements. The results were registered in hundredths of a second, and the better result was used for analysis. The measurement was performed on days without rain and/or strong wind (± 2 m/s). All subjects wore sportswear and running shoes (no spikes).

2.4.3. 20 m Running from a Block Start

The test was performed in a sports hall using a flat and hard surface. The test track was 20 m long and marked by start and finish lines. The starting block was placed behind the starting line, and subjects could adjust it according to their starting preferences. Photocells (Brower Timing System, Draper, UT, USA) used for electronic timing were placed at the start and finish lines. The Optojump Next optical system (Microgate, Bolzano, Italy) was set up along the measured track. The task was repeated twice with a rest interval of 15 min between test performances. The result was registered in hundredths of a second, and the best result was used for analysis.

2.4.4. 20 m Running from a Flying Start

The test was performed in a sports hall on a flat and hard surface. The test track was 20 m long and marked by start and finish lines and a 25 m distance for the start acceleration before the start line. Photocells (Brower Timing System, Draper, UT, USA) used for electronic timing were placed at the start and finish lines. The Optojump Next optical system (Microgate, Bolzano, Italy) was set along the measured distance (20 m). The subject was in a standing start position 25 m from the start line. The subject was allowed to start on his own and ran the 45 m distance with maximum effort. The task was repeated twice with a rest period of 15 min between test performances. The result was recorded in hundredths of a second, and the best result was used for analysis.

2.4.5. Unilateral Horizontal 20 m Cyclic Jumps

The test [26] was performed in a sports hall on a flat and hard surface, and the distance of 20 m was marked by start and finish lines. The results were registered electronically (Brower Timing System, Draper, UT, USA). The Optojump Next optical system (Microgate, Bolzano, Italy) was adjusted along the measured distance (20 m). The subject was in a standing start position behind the start line. After the measurement signal "set" and the start signal, the task began with the lifting of the front leg and the swinging of the contralateral arm. With unilateral horizontal cyclic jumps, the subject crossed the track in the shortest possible time. Timing began after the start signal of the measurer who started the time manually. Basic criteria had to be met for the correct execution of the jumps: start after the start signal and completion of the task to the finish line by jumping with only one leg with a cyclic arm swing. UHCJ is more of a fast stretch-shortening cycle, so we followed the criterion for a contact time of less than 250 ms on average. For most subjects, the first contact was greater than 250 ms, but subsequent contacts were shorter. The test was performed with the dominant leg. Before the test during the track and field classes, all subjects performed single leg jumps with both legs so that they knew which leg they could achieve a better result with. The task was repeated twice with the rest interval of 15 min between test performances. The result was recorded in hundredths of a second, and the best result was used for analysis. The test is described in more detail in the Appendix A (Table A1).

2.5. Data Processing Methods

For all variables, the basic descriptive parameters were calculated, and the normality of the distribution was tested using the Kolmogorov–Smirnov test at the significance level of $p \leq 0.05$. The prognostic validity of the motor test UHCJ20m compared to the MRLS20m, MRFS20m, and M100m tests was determined using simple regression analysis. Multiple regression analysis and stepwise regression analysis were used to determine the correlation between the kinematic parameters of the UHCJ20m test and the kinematic parameters and running performance of the MRLS20m, MRFS20m and M100m tests. The results were obtained using the Statistica 13.3 software package (TIBCO Software Inc., Palo Alto, CA, USA).

3. Results

3.1. Basic Statistic

The basic descriptive parameters of the subjects in the UHCJ20m, MRLS20m, MRFS20m, and M100m tests were calculated. The results of descriptive analysis (Table 1) show that the average result in the M100m test was 12.97 ± 0.54 s, while the fastest result was 11.36 s and the slowest was 14.47 s. The average result in the MRLS20m test was 3.43 ± 0.12 s, the fastest result was 3.13 s, and the slowest was 3.74 s. In the MRFS20m test, the subjects obtained an average result of 2.36 ± 0.10 s, while the fastest result of the 20 m run from the flying start was 2.06 s and the slowest was 2.72 s. In the last test, UHCJ20m, the average result was 4.41 ± 0.32 s, while the best result was 3.70 s and the slowest was 5.25 s. In all four tests, the results of the subjects were homogeneous and did not deviate significantly from the normal distribution of the results.

3.2. Correlation between Results in the UHCJ20m Test and Results in the M100m, MRLS20m, and MRFS20m Tests

Although the coefficients of the three simple regression analyses are statistically significant, the greatest correlation was found between the predictor variable UHCJ20m and the results of the MRFS20m and MRLS20m tests (Table 2). The results of the regression analysis showed a statistically significant moderate positive correlation (R = 0.534 and 0.486, respectively), while the coefficient of determination (R^2 = 0.285 and 0.236, respectively) implies that the independent variable explains 29% and 24% of the variance of the dependent variable.

Table 1. Descriptive statistics of tests.

N = 118	M ± SD	Min–Max	V	Skew	Kurt	Max D
M100m (s)	12.97 ± 0.54	11.36–14.47	0.29	−0.10	1.13	0.08
MRLS20m (s)	3.43 ± 0.12	3.13–3.74	0.02	−0.14	−0.13	0.04
MRFS20m (s)	2.36 ± 0.10	2.06–2.72	0.01	−0.12	1.38	0.07
UHCJ20m(s)	4.41 ± 0.32	3.70–5.25	0.10	0.30	−0.01	0.05

K-S0.05 = 0.13. Legend: N—number of subjects, M—arithmetic mean, Min—minimal result, Max—maximal result, V—variance, SD—standard deviation, Skew—skewness, Kurt—kurtosis, max D—maximal deviation of the relative cumulative empiric frequency from the relative theoretical frequency; M100m—100 m run, MRLS20m—20 m sprint start run, MRFS20m—20 m flying start run, UHCJ20m—20m unilateral horizontal cyclic jumps.

Table 2. The results of a simple regression analysis between the predictor variable UHCJ20m and the criterion variables M100m, MRLS20m, and MRFS20m.

UHCJ20m	R	R^2	F (1,116)	SEE	b *	b	t (116)	*p*
M100m	0.376	0.141	19.042	0.499	0.376	0.630	4.364	0.000 *
MRLS20m	0.486	0.236	35.893	0.108	0.486	0.187	5.991	0.000 *
MRFS20m	0.534	0.285	46.257	0.088	0.534	0.174	6.801	0.000 *

Legend: UHCJ20m—unilateral horizontal cyclic jumps 20 m, M100m—100 m run, MRLS20m—20 m sprint start run, MRFS20m—20 m sprint flying start run, R—coefficient of correlations, R^2—coefficient of determination, F—f test value, SEE—standard error of the estimate, b *—regression coefficient, b—non-standardized regression coefficient, *t*-value, * significant at $p \leq 0.05$.

3.3. Correlation between Kinematic Parameters of the UHCJ20m Test and Kinematic Parameters of the MRLS20m and MRFS20m Tests

Table 3 shows the descriptive statistics of the kinematic parameters of the tests. The results show that the subjects achieved an average speed (v) of 4.56 ± 0.33 m/s in the UHCJ20m test, with the slowest subject achieving 3.81 m/s and the fastest 5.41 m/s. The arithmetic mean of SF was 2.26 ± 0.41 str/s, with the lowest being 1.78 and the highest being 4.49 str/s. The average SL achieved in the test was 2.06 ± 0.28 m, with the shortest stride being 1 m and the longest stride being 2.87 m. The ground contact time, i.e., the average CT during the amortization and takeoff phases was 193.39 ± 25.01 ms, where the shortest average time was 90.89 ms and the longest was 243.63 ms. The average flight time of the subjects (FT) in the test was 259.32 ± 34.23 ms. The shortest flight time was 119.33 ms, and the longest was 335.14 ms. The test also calculated the number of steps (SN) required to cover the 20 m distance. On average, subjects required 9.14 ± 0.87 strides to cover 20 m. The subject with 7 jumps had the lowest number of steps, whereas the subject with 11 jumps had the greatest number of steps.

Table 3. Descriptive statistics of kinematic parameters of the UHCJ20m, MRLS20m, and MRFS20m tests.

N = 118	Variable	M ± SD	Min–Max	V	Skew	Kurt	Max D
UHCJ20m	v (m/s)	4.56 ± 0.33	3.81–5.41	0.11	0.10	−0.15	0.05
	SF (str/s)	2.26 ± 3.84	1.78–4.49	0.16	3.84	17.04	0.05
	SL (m)	2.06 ± 0.28	1.00–2.87	0.08	−1.14	4.17	0.06
	CT (ms)	193.39 ± 25.01	90.89–243.63	625.45	−1.21	3.32	0.05
	FT (ms)	259.32 ± 34.23	119.33–335.14	1171.3	−1.61	4.88	0.06
	SN (n)	9.14 ± 0.87	7.00–11.00	0.76	−0.21	−0.36	0.20

K-S0.05 = 0.13. Legend: N—number of subjects, M—arithmetic mean, Min—minimal result, Max—maximal result, V—variance, SD—standard deviation, Skew—skewness, Kurt—kurtosis, max D—maximal deviation of the relative cumulative empiric frequency from the relative theoretical frequency; UHCJ20m—20m unilateral horizontal cyclic jumps, v—average speed, SF—average step frequency, SL—average step length, CT—average contact time, FT—average flight time, SN—average number of steps.

Multiple regression analysis was used to determine the correlation between the kinematic parameters of the UHCJ20m test and the final results of the M100m, MRLS20m, and MRFS20m tests. Due to the direct dependence of the average movement speed in the UHCJ20m test and the final results in the other tests, this variable was omitted from further analysis. Similarly, due to the occurrence of multicollinearity and to exclude variables that did not provide new information about the correlation between the set of predictor variables and the criterion variable, a stepwise regression analysis was used.

Stepwise regression analysis identified two of four statistically significant kinematic parameters that contained the most information about correlation with the criterion variable (Table 4). The entire set of predictors showed correlation values with criterion (R = 0.371; R^2 = 0.138). The variables SL (p = 0.008) and CT (p = 0.043) were the only ones that significantly correlated with 100 m sprint success, whereas the other variables did not contain any new information.

Table 4. Results of stepwise forward regression analysis of the set of kinematic parameters of the UHCJ20m test and results in the M100m test.

M100m	**R = 0.371**	**R^2 = 0.138**	**F(4,113) = 4.507**		***p* < 0.002**	**SEE 0.507**
UHCJ20m	**b ***	**Part. r**	**b**	**Rsquare**	**t (114)**	***p***
SN	0.129	0.104	0.079	0.435	1.109	0.270
CT	0.260	0.189	0.006	0.529	2.043	0.043 *
SL	−0.516	−0.245	−1.001	0.793	−2.689	0.008 *
FT	0.284	0.163	0.004	0.708	1.758	0.081

Legend: UHCJ20m—unilateral horizontal cyclic jumps 20 m, M100m—100 m run, R—coefficient of correlations, R^2—coefficient of determination, F—f test value, SEE—standard error of the estimate, t—value, b *—regression coefficient, Part. r—partial correlation coefficient, b—non-standardized regression coefficient, t—*t* value, SN—average number of steps, CT—average contact time, SL—average step length, FT—average flight time, * significant at $p \leq 0.05$.

Table 5 shows the results of the stepwise backward regression analysis of the set of kinematic parameters in the UHCJ20m test and the results in the MRLS20m test. A kinematic parameter showing a negative correlation between SN in the UHCJ20m test and the final result in the MRLS20m test is highlighted. The correlation coefficient is R = 0.383, and the coefficient of determination is R^2 = 0.147 at the significance level of $p < 0.001$, which means that the subjects with a lower number of steps/jumps had a better result in the start acceleration run.

Table 5. Results of stepwise backward regression analysis of the set of kinematic parameters of the UHCJ20m test and the results in the MRLS20m test.

MRLS20m	**R = 0.383**	**R^2 = 0.147**	**F(4.116) = 19.96**		***p* < 0.001**	**SEE 0.114**
UHCJ20m	**b ***	**Part. r**	**b**	**Rsquare**	**t (114)**	***p***
SN	0.383	0.383	0.054	−0.000	4.468	0.000 *

Legend: UHCJ20m—unilateral horizontal cyclic jumps 20 m, MRLS20m—20 m sprint start run, R—coefficient of correlations, R^2—coefficient of determination, F—f test value, SEE—standard error of the estimate, b *—regression coefficient, Part. r—partial correlation coefficient, b—non-standardized regression coefficient, t—value, SN—average number of steps, * significant at $p \leq 0.05$.

Table 6 shows the results of the stepwise regression analysis of the set of kinematic parameters of the UHCJ20m test without average speed and the result in the MRFS20m test. The results show the exclusion of the kinematic variables from the previous set, which are statistically significant. Their coefficient of multiple correlation with the criterion variable was R = 0.486, while the coefficient of determination was R^2 = 0.236. The correlation SL variable's coefficient of correlation Part. r = −0.469, whereas the CT variable had a somewhat lower coefficient of correlation Part. r = 0.425 with the result of the UHCJ20m test at a statistically significant difference at $p < 0.001$. The results imply that subjects who had a shorter ground contact time and a longer jump had better results in the maximum running speed assessment test.

Table 6. Results of stepwise forward regression analysis of the set of kinematic parameters of the UHCJ20m test and the results in the MRFS20m test.

MRFS20m	R = 0.486	R^2 = 0.236	F(2,115) = 17,776		p < 0.001	SEE 0.092
UHCJ20m	**b ***	**Part. r**	**b**	**Rsquare**	**t (114)**	***p***
SL	−0.607	−0.469	−0.228	0.417	−5.687	0.000 *
CT	0.538	0.425	0.002	0.417	5.041	0.000 *

Legend: UHCJ20m—unilateral horizontal cyclic jumps 20 m, MRFS20m—20 m flying start run, R—coefficient of correlations, R^2—coefficient of determination, F—f test value, SEE—standard error of the estimate, b *—regression coefficient, Part. r—partial correlation coefficient, b—non-standardized regression coefficient, t—value, SL—average step length, CT—average contact time, * significant at $p \leq 0.05$.

4. Discussion

The aim of this research study was to determine the correlation (predictive validity) of the UHCJ20m test in regards to the 100 m sprint (M100m), start acceleration (MRLS20m), and maximum running speed (MRFS20m). In addition, this research study aimed to determine the correlation between the kinematic parameters of the UHCJ20m motor test and performance in the 100 m sprint, start acceleration, and maximum running speed. The results of this study showed a moderate correlation in all tests (MRLS20m (R = 0.49), MRFS20m (R = 0.53), and M100m (R = 0.38)) with UHCJ20m.

The results of the regression analysis confirmed a moderate significant correlation between the UHCJ20m test and the results in the 100 m sprint (Table 2). Explosive strength was found to have a dominant influence on sprint running results [11,13–17,21,22,30–34]. For this reason, in processes of selection, control, and monitoring of sprinters, tests measuring explosive strength in the form of jumps and throws were used. The results of this research study were somewhat surprising, considering that many authors have found a much greater correlation between results in vertical and horizontal jumps and speed in 100 m sprints [11]. In simple terms, sprinting essentially consists of multiple single-legged or unilateral jumps that require an optimal relationship between stride length and frequency to achieve the greatest possible sprinting speed. Because running, especially sprinting, requires the use of both horizontal and vertical forces [8,35], Holm et al. [8] found that the results of tests involving horizontal jumps were better predictors of sprinting ability than vertical jumps. Sprint performance, like jump performance, depends on muscle contractility, the type and number of muscle fibers, inter/intramuscular coordination, and neural adaptation and activity [36–38]. For these reasons, a better prediction of 100 m sprint results based on the results of the UHCJ20m test was expected, as previously found by Babić [27] for the 60 m sprint in girls. It was previously found that the correlation between unilateral horizontal jumps and sprint time and speed was greater in sprinters than in high school students [11]. It is likely that the same trend is present in the population of other sports that do not specialize in the 100 m sprint running. When analyzing the results of this study on the performance of the subjects in the M100m sprint test (Table 1) and comparing them with the results of elite sprinters [39], it is obvious that the results of the subjects were much worse, but when comparing these results with the results of other populations of athletes and the population of sports students, they were similar or slightly better [32,38]. Some authors have provided the following values of sports students: 12.20 ± 0.36 s [11], 13.00 ± 0.51 s [38], and 12.60 ± 0.9 s [39]. Elite sprinters who competed in the finals of the Olympic Games in 2008 and 2012 had average results of 9.96 ± 0.05 s and 9.86 ± 0.10 s, respectively, not including the results of Usain Bolt, who ran in these finals [40]. Slovenian elite sprinters run the 100 m on average in 10.52 ± 0.19 s. The difference in the results of the 100 m sprint between elite sprinters and students is 3 s and 2.5 s, respectively, suggesting a specific training process, a learning process, genetically inherited abilities, and several years of selection of sprinters. Babić [32] investigated the 100 m sprint in student athletes and obtained similar results, which averaged 13.00 ± 0.51 s, confirming similar speed/sprint abilities of the subjects and also a greater variability of results within the group of subjects.

The 100 m sprint run can be divided into start, start acceleration, maximum running speed, and deceleration, considering structural features [32,41–43]. The results of the regression analysis used to determine the correlation between the predictor variable, the result in the UHCJ20m test, and the result in the MRLS20m test showed a statistically significant correlation (Table 2). Along with this result, it was expected that the correlation coefficient of the results obtained in these two tests would be higher because the existing data on horizontal jumps showed a greater correlation with sprinting at 5, 10, 20, and 25 m. The correlation coefficients differ with respect to the type of jumps (bilateral, unilateral, or cyclic) and the length of the distance used to measure start acceleration, varying from r = 0.66–0.86 [5,9,20,21,24]. The start acceleration run consists of several phases: the initial acceleration from 0–12 m, characterized by a constant increase in stride length; the main acceleration from 12–35 m; and the third phase, which is present only in elite sprinters and occurs from 35–60 m. Elite sprinters reach the maximum running speed between 50 and 70 m [11,41,42,44]. According to the available research studies [38], student athletes reach maximal running speed around 30 m, which implies lower speed in the first phase of sprinting as well as in the phase of running at maximal speed. Due to the similar movement pattern and the exertion of a large concentric force and thus a large running speed during the acceleration phase, horizontal jumps have shown a great predictive value for the start acceleration run [11,22,45]. Rimmer and Sleivert [46] suggested horizontal jumps as a specific exercise for the development of start acceleration. The reason why a lower correlation coefficient was found in this study than in other studies could be due to an insufficient level of motor knowledge and lower extremity muscle strength of the subjects. The subjects learned and practiced block starts during class, but the number of iterations may not have been sufficient for the subjects to master the movement structure at a serious level because starts and block clearances are very complicated movement structures. In research studies that investigated the relationship between jump and start acceleration and running speed, in most cases, subjects performed 5 m, 10 m, 20 m, or 30 m sprint tests from a standing position, which allowed them to achieve a higher speed over shorter distances [5,7–9,47]. Maćkala et al. [11] used standing 10 jumps and standing 5 jumps in their test battery, which are structurally similar to the UHCJ20m, only the final outcome is different as these jumps measure the total distance jumped, whereas the UHCJ20m test measures the time taken to complete the task. Standing 10 jumps and standing 5 jumps differ because certain kinematic parameters change when measuring the total length of the jumps, while tests that measure the time required to complete jumps over a given distance require the subject to find an optimal balance between parameters such as stride length and frequency, ground contact time, and flight time. In a research study on a student population that exercises frequently, Maćkala [11] found a statistically significant correlation between S5J and 10 m sprint time ($r = -0.70$). It could be concluded that performing a series of connected unilateral jumps is more demanding for the non-sprinter population and therefore their results are worse than shorter and less demanding tests used to assess lower extremity explosive strength. In their study, Meylan et al. [13] investigated the ground reaction forces in the concentric (505.9 ± 91.9 N) and eccentric part (392.7 ± 110.1 N) of the foot contact during the horizontal unilateral HCMJ in team athletes. According to Hunter et al. [35], the relative horizontal (R^2 = 61%) and propulsive (R^2 = 57%) momentum of ground reaction forces during sprinting are better predictors of success in the 16 m sprint than vertical indicators of forces. Start and start acceleration have similar requirements, as the ability to generate a large horizontal force at the beginning of the distance determines success in sprint running [48]. Mero [49] found that the average horizontal propulsive force of sprinters in the first stride after the block clearances is 526 N. This is the horizontal force of the sprinter. It is the horizontal velocity of movement of the body's center of gravity that is the key factor in generating a large vertical force of ground reaction, which is present in hurdling, unilateral jumps, and specific horizontal jumps used by athletes that generate the greatest horizontal velocity [50]. It could be speculated that untrained and/or insufficiently trained individuals might have problems tolerating these forces when performing jumps, based on the authors' experience.

The values of the results of the regression analysis used to determine the functional relationship between the results of the predictor variable UHCJ20m and the criterion variable MRFS20m implied a moderate correlation, i.e., the influence of the unilateral cyclic jumps on the result in the test of the evaluation of the maximum running speed (Table 2). The data obtained showed that performance in the UHCJ20m test had greater predictive power for the MRFS20m test results than for the M100m and MRLS20m test results. Other research studies [6,9,47,51] also found that horizontal jumps were more strongly correlated with maximum running speed than vertical jumps. The results of this research study confirmed the correlation between horizontal jumps and maximal running speed. The UHCJ20m [26] is a test of horizontal direction, unilateral and cyclic in nature, unlike a large number of horizontal jumps in many research studies, which include jumps such as STJ [5,6,24,29] S5J [11] and UHCJ30m [27,30].

The most commonly used and analyzed jumps in sprinting are the SLJ, the standing unilateral horizontal long jump, the drop horizontal jump, the drop unilateral horizontal jump, the STJ, and the S5J. Only the last two jumps are unilateral (although the take-off is bilateral) and cyclic (number of connected unilateral jumps). The greater the number of horizontal unilateral jumps (more connected jumps), presumably the better the predictability of the maximum running speed. Maćkala [11] found a statistically significant correlation between the S10J test results and the 100 m sprint ($r = -0.83$), whereas the correlation between S10J and the 30 m sprint time was weaker ($r = -0.67$). The S5J results showed the same trend with slightly lower values for both distances. The UHCJ20m test results in this research study showed a lower correlation ($r = 0.53$) but can still serve as a predictor of success in sprinting, more specifically, the maximum running speed. It is likely that the correlation between the two tests would be higher/stronger if the research study had been conducted on elite athletes, due to their specific leg strength and the level of upper body strength [11]. Due to insufficiently developed musculature and knowledge of the specific movement, the subjects in this research study did not perform unilateral jumps at the level that sprinters would likely perform.

To determine the correlation between the kinematic parameters of the UHCJ20m test and success in the M100m, MRLS20m, and MRFS20m tests, multiple regression analysis was performed (Tables 4–6). Due to the direct dependence of movement speed and final score on the set of predictor variables formed by the kinematic parameters, speed was not included in further analysis as it is the only variable that is statistically significantly correlated with success in sprint running. Furthermore, due to the occurrence of multicollinearity, a stepwise multiple regression analysis was performed. A correlation ($R = 0.37$) was found between the set of four variables and the M100m test results. Two statistically significant parameters, SL and CT, were highlighted, which carry most of the information about the correlation between predictors and criterion (Table 4). The most important parameter was the average SL, which is important for predicting the results of the M100m test. Many authors investigated the relationship between SL and SF in relation to the achievement of maximal running speed in all phases of sprint running in athletes of different levels, from elite athletes [42,52–57] to non-sprinter athletes [38,58]. Maćkala et al. [11] state that some research studies have found SL as the most significant parameter for the development of maximal running speed, whereas other research studies state SF as the most significant factor. An application of vertical and horizontal types of jumping exercises could contribute to longer SL [11,59,60]. However, Čoh et al. [61] claim that CT is the most important kinematic parameter in sprint running that distinguishes better and weaker sprinters. Changes in CT bring changes in SF values, which are also influenced by other parameters. Exercises targeting lower extremity explosive strength, especially horizontal jumps, may influence CT shortening and thus other parameters responsible for achieving higher sprint running speed. Jumps are specific training operators that use the stretch-shortening cycle to develop acceleration [46], and these types of exercises have a similar ground contact time to start acceleration running [11].

Block clearance and start acceleration (Table 5) were correlated with SN in the UHCJ20m test, which can be explained by the specificity of start and acceleration, i.e., the need to generate large muscle force, which also manifests itself in horizontal jumps through explosive strength and the longest possible jump. Subjects who had a lower number of steps/jumps also had a better result in the MRLS20m test. The importance of the number of steps, i.e., optimal stride length, is theoretically calculated using the formula presented by Donatti [62], while Čoh et al. [61] concluded that better sprinters perform fewer strides than worse sprinters and deviate less from the optimal number of steps calculated by Donatti [62]. In the same research study, Čoh et al. [61] stated that average ground contact time is an important indicator that differentiates between better and worse sprinters in start acceleration running. In this case, SL, FT, and CT also play an important role in the UHCJ20m test and the prognostic possibility of the results in the start acceleration run represented by the MRLS20m test.

The stepwise forward regression analysis (Table 6) identified parameters that carry the most information and implied how SL and CT in the UHCJ20m test are parameters that can be associated with successful running in the MRFS20m test. Running at maximum speed requires the sprinter to have an optimal ratio of SL and SF, which is also influenced by other kinematic parameters; therefore, the UHCJ20m test requires an optimal SL and SF, to achieve the maximum possible movement speed. The stride length depends mainly on body height and lower limb length [38], but also on ground contact time, flight time, and strength (especially of the lower limbs). Ground contact time in the acceleration phase lasts longer than in the running phase at maximum speed, while flight time is inversely proportional. Subjects in this research study had an average SL of 2.06 m and in the UHCJ20m test their SL averaged 2.00 m. The average SL of elite athletes in the maximum speed running phase of the 100 m sprint at maximum speed was 2.21 m [61], i.e., 2.45 m [63], whereas the average SL of student athletes was 2.01 m [38]. In conclusion, a greater stride/jump length in the UHCJ20m test is also important for predicting the results in the MRFS20m test, of course, as long as SF remains stable, and finally, horizontal speed.

The basic limitation of this study is the subject sample, which was a random sample that refers to the students who were positively selected for the sport but had no serious and professional training in sprint running. It is likely that using a representative sample of elite sprinters would yield even stronger and more comprehensive correlations. An additional limitation was the lack of other kinematic analyses (e.g., intersegment angle, angular velocity) and ground reaction force analyses that could provide additional information about the quality of a particular performance.

5. Conclusions

The UHCJ20 test proved to be a statistically significant predictor of sprint running success, especially for the maximal speed running segment. Kinematic parameters found to be statistically significant predictors of success in this study were SN for the MRLS20m test, while they were SL and CT for the MRFS20m and M100m tests, respectively. We speculate that this test would be a good tool for involving athletes in the training process after lower extremity injuries, if the criterion of the duration of contact of the foot with the ground was excluded, comparing the results with the injured and the uninjured leg. This research study is one of the rare studies in the field of the correlation/relationship between unilateral jumps and sprinting conducted on a larger sample (i.e., more than 100 subjects). Our recommendation for future research studies is to repeat this experiment with a population of sprinters to obtain more complete information about the mutual correlation between the tests and the corresponding kinematic parameters. Furthermore, for different sports and coaches, it would be useful to study the same questions with different age and gender groups, as well as with athletes of different sports and different training levels.

Author Contributions: V.B., I.M. and A.D.; designed and performed the experiment, A.D., I.M. and V.B.; methodology, A.D.; software, I.M. and V.B.; formal analysis, I.M., V.B. and A.D.; writing—original draft preparation, I.M., V.B., A.D. and M.Č.; writing—review and editing. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Faculty of Kinesiology, University of Zagreb, Javna agencija za raziskovalno dejavnost Republike Slovenije grant number P5-0142 and Faculty of Economics & Business, University of Zagreb.

Institutional Review Board Statement: The study was conducted in accordance with the guidelines of the Declaration of Helsinki and approved by the Ethics Committee of the Faculty of Kinesiology, University of Zagreb (No. 42/2018, 30 October 2018.).

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

Data Availability Statement: All the data and reported results are available on request to the corresponding author.

Acknowledgments: The authors thank the Faculty of Kinesiology of the University of Zagreb for financial support in this project as well as all the participants in this research study.

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

Appendix A

Table A1. Representation of the standardization of the UHCJ20m test [26].

Test: 20-m Unilateral Horizontal Cyclic Jumps	
TEST CODE	**UHCJ20m**
MEASUREMENT PURPOSE	**Explosive Strength of Legs (Elastic Strength)**
NECESSARY EQUIPMENT	1. Laboratory: a straight, smooth, and hard surface with a minimum of 30 m in length and 1 m in width; the start and finish lines were marked 20 m apart; BROWER Timing System photocells; OPTOJUMP optical system; and computer with an appropriate software; a starting signal apparatus. 2. Field: a straight, smooth, and hard surface with a minimum of 30 m in length and 1 m in width; the start and finish lines were marked 20 m apart; a stopwatch; a starting signal apparatus.
TEST EXECUTION DESCRIPTION	The subject stands behind the start line in the position for a standing start with one leg nearer to the start line. After the measurer's command, "on your marks," and the start signal, the subject begins and the task executes and sets o_ with the front leg and by the alternate arm swing (not simultaneous). The subject covers the distance in the shortest possible time using the same leg jumps. Correctness criteria: the task execution begins only after the start signal, and the task is completed via the marked distance to the finish line by jumping on the same one leg using the alternate arm swings. The task is executed three times. Active rest intervals (stretching and light jogging) between the attempts should ensure full recovery of the participant.
INSTRUCTIONS TO SUBJECTS	The task is demonstrated and elaborated: "This is a test used to assess explosive strength of the legs. Your goal is to cover the 20 m distance using unilateral jumps in the shortest possible time starting from the standing start position and setting off with the front leg in the start position after the measurer's command, 'on your marks,' and the start signal. You can use alternate arm swings (as in running). Try to find your best balance between your jump length and the frequency in your efforts to attain the greatest speed of movement possible."

Table A1. *Cont.*

Test: 20-m Unilateral Horizontal Cyclic Jumps	
TEST CODE	**UHCJ20m**
MEASUREMENT PURPOSE	**Explosive Strength of Legs (Elastic Strength)**
RESULTS DETERMINATION	The result is the time needed to cover the 20 m distance using unilateral horizontal cyclic jumps. The task is performed three times. The best attempt is recorded as the test outcome. (If any sophisticated additional equipment is employed in a laboratory, the kinematic measures, such as the jump length, the jump frequency, the speed of movement, teh number of jumps, etc., are used along with the end results). The result is expressed in tenths of a second.

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