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# Kinematic Analysis of High Jump Using the Scissors Technique

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## *ABSTRACT*

The purpose of the research is to determine the kinematic parameters that are key to achieving the best high jump results with the scissors technique in children, as well as the mutual correlations in the approach and take-off phases. As many as 123 subjects between the ages of 7 and 12 (9.20 ± 1.33 years old) participated in the research. The respondents were members of the Kvarner athletics club. The high jump using the scissors technique was recorded with a Sony RX10 II video camera. The kinematic analysis was carried out using the software Kinovea 0.9.5. Multiple linear regression was used to examine the association of nine predictor variables with the bar height criterion, while to determine significant correlations between kinematic parameters, an analysis of Pearson's correlation coefficients was performed. The most significant findings of the research show that the predictors explain a significant part of the variance (60.4%) of height of the bar ($F (9. 112) = 18.98$; $p < 0.001$). Significant predictors of height of the bar are: the duration of the penultimate stride in the run-up ($\beta = - 0.43$; $p < 0.01$), length of the last stride in the run-up ($\beta = 0.30$; $p < 0.01$), length of the penultimate stride in the run-up ($\beta = 0.41$; $p < 0.01$) and ankle angle ($\beta = 0.21$; $p < 0.01$). Certain kinematic parameters are relevant for success in the high jump.

**Keywords:** high jump, scissors technique, kinematic analysis, advancement of the technique, children

## INTRODUCTION

The high jump is an athletic discipline with numerous modifications of techniques that have developed throughout history. Although today the most well-known and most commonly used is the back or Fosbury flop technique due to its efficiency, in working with children, the scissors technique is most often used. It got its name because of its scissor-like crossing over the bar in the flight phase. The goal of the high jump is to bring the centre of gravity of the body to the highest point when crossing the bar (Saratlija, 2020), and it consists of four key phases: the approach phase, the take-off phase, the flight phase and the landing phase. In working with children, the scissors technique is often used as an effective method for acquiring and perfecting the connection between the approach phase and the take-off phase. Both mentioned phases have a key role in determining the quality of the performance, i.e. they have a direct impact on the height and technical performance of the jump. The optimal conditions for the take-off phase are achieved in the approach phase (Saratlija, 2020), while the transformation of horizontal to vertical speed occurs in the reflection phase, determining thus the efficiency of the jump (Dapena, 2002). A suitable approach enables reaching the take-off phase in the correct position with an optimal speed that ensures an efficient jump (De Pano et al., 2012).

It is precisely the determination of certain kinematic parameters that allows insight into the structure of motion. Kinematics of motion implies the observation of bodies in motion, i.e. it includes the study of the magnitude, order and time of motion without taking into account the forces that cause or result from motion (Hall, 2012). Kinematic analysis provides experts in the field of sports with valuable information that can lead to an effective transformation process, but can also be decisive in moments of competition. In the background of perfecting the technique of some motor knowledge is the process of motor learning. Motor learning refers to the process of forming motor skills that can be defined as the learned ability to achieve certain results and external goals with maximum certainty of performance and minimal expenditure of energy and time (Jarvis, 1999). Motor knowledge can be defined as a motor record located in the motor areas of the central nervous system, and at a perfected level it enables the performance of a purposeful motor movement (Neljak, 2013). Considering the fact that the optimal efficiency of motor skills is achieved only through practice and improvement (Logan et al., 2012), the insight into the kinematic analysis determines the key parameters that can improve the high jump technique. Differences affecting the sports result are generally attributed to better technical performance, which is often the result of different individual kinematic parameters' value (Pavlović, 2017).

Previous research mainly deals with the kinematic analysis of the high jump at elite athletic competitions, where data on top athletes are investigated. The most frequently observed kinematic parameters are: flight height of the body centre of gravity, height of the hips above the bar, vertical velocity of the centre of gravity of the body at the end of the take-off, take-off angle, take-off duration, angle of entry into the take-off, maximum height of the centre of gravity of the body at the moment of crossing the bar, horizontal velocity of the centre of gravity of the body of the penultimate stride in the run-up, length of last stride in the run-up, length of penultimate stride in the run-up, etc. (Blažević, Antekolović, & Mejovšek, 2006). It is possible to notice that most of the mentioned parameters refer to the approach and take-off phase, as in this research. According to the available literature, the only research which dealt with the high jump using the scissors technique on a sample of children was written by Ljubičić (2022), where the differences in the effects of bilateral versus unilateral training using specific high jump exercises, as well as the changes in the neuromuscular function were determined.

Since there are no studies dealing with the kinematic analysis of high jump in children, this research represents a significant contribution to the scientific literature and to experts working in practice. Therefore, this research is based on the kinematic analysis of the approach and take-off phase in working with children, which will allow experts and children to better understand each high jump sequence and to precisely identify the areas that require improvement in order to achieve the highest possible result and quality of the jump. Moreover, it is possible to monitor changes and determine parameters that are important for the development of the technique, and in addition, it is possible to prevent factors of risk for injuries. The purpose of this research is to determine the kinematic parameters that are key to achieving the best high jump results of the scissors technique in children, as well as the mutual correlations in the approach and take-off phases.

## METHODS

### Sample of participants

There were 123 participants in the research, namely 53 boys (43.1%) and 70 girls (56.9%). The participants were members of the athletics club Kvarner from Rijeka, between 7 and 12 years of age (9.20 ± 1.33 years old). Table 1 shows sample data on basic morphological measures.

**Table 1.** Morphological measures of the sample

| | N | Min | Max | M | SD |
|---|---|---|---|---|---|
| **Age** | 113 | 6.32 | 11.94 | 9.20 | 1.33 |
| **BH (cm)** | 107 | 109.30 | 160.60 | 137.57 | 10.04 |
| **BM (kg)** | 113 | 18.80 | 51.20 | 33.49 | 7.46 |
| **BMI (kg/m²)** | 107 | 13.28 | 23.31 | 17.51 | 2.38 |

**Legend**: BH – body height (centimetres), BM – body mass (kilograms), BMI – body mass index (kg/m²), N – number of respondents, Min – minimal result, Max – maximal result, M – arithmetic mean, SD – standard deviation

### *Sample of variables*

The set of variables includes kinematic parameters that relate to the success of high jump results using the scissors technique. Parameters related to the duration of foot contact with the ground are expressed in milliseconds, jump height, as well as stride lengths are expressed in centimetres, while the angles are shown in degrees. The research included an analysis of 10 variables, where there are nine independent variables, while the dependent variable is the result of the high jump (cm) (Table 2).

**Table 2.** List of variables with abbreviations and measuring units

| Variable | Abbreviation | Measuring unit |
|---|---|---|
| Height of the bar | HB | centimetres (cm) |
| Duration of take-off | DTO | milliseconds (ms) |
| Duration of the last stride in the run-up | DLS | milliseconds (ms) |
| Duration of the penultimate stride in the run-up | DPLS | milliseconds (ms) |
| Distance between take-off point and landing | DTL | milliseconds (ms) |
| Length of the last stride in the run-up | LLS | centimetres (cm) |
| Length of the penultimate stride in the run-up | LPS | centimetres (cm) |
| Angle in the knee of the take-off phase – amortisation | AATK | ° |
| Angle in the hip of the take-off phase – amortisation | AATH | ° |
| Angle in the ankle of the take-off phase - amortisation | AATA | ° |

### *Measurement protocol*

Parents/guardians of the children were informed and familiarized with the research plan, possible risks and benefits of participation before the beginning of the measurements, and they signed an informed consent on participation. A standardized warm-up was performed before the measurement procedure. The high jump using the scissors technique was recorded with a Sony RX10 II video camera (high speed - 250 images per second). The highest jumped height was recorded, and the criterion for a successful jump was jumping over the bar with a one-legged take-off with the outer leg in relation to the bar. Participants had three attempts at each height. The measurement ended if the participant independently gave up further jumping or knocked down the bar three times. All participants had the same landing conditions to avoid possible variations in the approach to the slat. The height of the bar was determined with the help of the high jump standards used in official athletic competitions and the referee's tape measure.

### *Calculating kinematic data*

The best achieved result, i.e. the highest jump was included in the further processing. Kinematic analysis was carried out in the program Kinovea 0.9.5., which enables the analysis of slow-motion videos. The beginning of the duration of contact of the foot with the ground was marked by the image in which the foot made the first contact with the ground, and it ended with the image before the foot leaves the ground. The length of the stride was determined as the distance between the feet (toes-toes), and the angles were determined in the first phase of take-off at the moment of maximum flexion (amortization) in the knee of the take-off leg. Based on the given parameters, the Kinovea program calculated the duration of contact of the foot with the ground, the distance between the point of take-off and the landing place, the length of the stride in the last and penultimate stride, and the angles in the knee, hip and ankle joints.

### *Statistical data processing*

Statistical analysis was performed with the help of the SPSS 25 software package. Basic descriptive statistics were calculated for all observed variables: minimum score, maximum score, arithmetic mean, standard deviation, skewness and kurtosis index. In order to examine the connection of nine predictor variables with the bar height criterion, multiple linear regression was used, and the prerequisites for conducting the analysis were previously met. To determine statistically significant correlations between kinematic parameters, an analysis of Pearson's correlation coefficients was performed.

## RESULTS

Descriptive statistics include the display of one dependent variable HB and nine independent variables related to kinematic parameters (Table 3). Considering the large sample and the indices of symmetry (Skewness; the highest index is 1.06) and flatness (Kurtosis; the highest index is 1.46), it can be concluded that the distributions of the variables deviate negligibly from the normal distribution. A large dispersion in standard deviation values is determined for all observed parameters. Kinematic parameters with the greatest dispersion in values are: duration of reflection

(SD = 39.76) and duration of the third stride (SD = 31.87). The lowest dispersive values are: ankle angle (SD = 5.90), knee angle (SD = 8.77) and hip angle (SD = 11.91).

**Table 3.** Descriptive statistics

| Variables | N | Min | Max | M | SD | Skewness | Kurtosis |
|---|---|---|---|---|---|---|---|
| HB (cm) | 123 | 53.00 | 128.00 | 86.81 | 14.75 | 0.02 | -0.39 |
| DTO (ms) | 122 | 160.00 | 352.00 | 228.85 | 39.76 | 1.06 | 1.46 |
| DLS (ms) | 123 | 132.00 | 288.00 | 215.02 | 28.20 | 0.11 | 0.22 |
| DPLS (ms) | 123 | 136.00 | 292.00 | 202.42 | 31.87 | 0.41 | -0.19 |
| DTL (cm) | 123 | 7.09 | 95.66 | 43.09 | 17.12 | 0.59 | 0.43 |
| LLS (cm) | 123 | 45.28 | 182.89 | 113.79 | 22.51 | -0.04 | 0.47 |
| LPS (cm) | 123 | 64.28 | 179.69 | 112.38 | 25.00 | 0.27 | -0.30 |
| AATK (°) | 123 | 104.00 | 154.40 | 129.64 | 8.77 | -0.28 | 0.46 |
| AATH (°) | 123 | 114.70 | 174.00 | 151.74 | 11.91 | -0.49 | 0.38 |
| AATA (°) | 123 | 92.10 | 119.90 | 103.14 | 5.90 | 0.44 | 0.07 |

**Legend**: N – number of participants, Min - minimal result, Max – maximal result, M – arithmetic mean, SD – standard deviation, Skewness – symmetricity index, Kurtosis – flatness index

Multiple linear regression was used to test the correlation of nine predictor variables with the HB criterion. The results of the regression analysis show that the predictors explain a significant part of the variance (60.4%) of HB ($F$ (9. 112) = 18.98; $p < 0.001$). Significant predictors of HB are: DPLS ($\beta$ = - 0.43; $p < 0.01$), LLS ($\beta$ = 0.30; $p < 0.01$), LPS ($\beta$ = 0.41; $p < 0.01$) and AATA ($\beta$ = 0.21; $p < 0.01$). A higher HB score is associated with a lower DPLS score, a higher LLS score, a higher LPS score, and a higher AATA score.

**Table 4.** Regression analysis results for the criterion height of the bar

| | B | SE B | β | t | p |
|---|---|---|---|---|---|
| (constant) | 63.16 | 19.94 | | 3.17 | 0.002 |
| DTO | 0.01 | 0.03 | 0.01 | 0.18 | 0.857 |
| DLS | -0.05 | 0.04 | -0.10 | -1.27 | 0.206 |
| DPLS | -0.20 | 0.04 | **-0.43** | -4.75 | **0.000** |
| DTL | 0.02 | 0.06 | 0.02 | 0.29 | 0.770 |
| LLS | 0.19 | 0.06 | **0.30** | 3.02 | **0.003** |
| LPS | 0.24 | 0.06 | **0.41** | 4.21 | **0.000** |
| AATK | -0.27 | 0.15 | -0.17 | -1.79 | 0.075 |
| AATH | 0.05 | 0.09 | 0.04 | 0.51 | 0.610 |
| AATA | 0.51 | 0.18 | **0.21** | 2.78 | **0.006** |
| $R$=0.777. $R^2$ = 0.604 | | | | | |
| $F$ (9. 112) = 18.98; $p < 0.001$ | | | | | |

**Legend**: B – nonstandardised regression coefficient, SE B – standard error B, β - standard regression coefficients and their significance, R – multiple correlation coefficient, $R^2$ – determination coefficient

To determine statistically significant correlations between kinematic parameters, an analysis of Pearson's correlation coefficients was performed (Table 5). DTO is statistically significantly positively correlated with DLS (r = 0.43) and DPLS (r = 0.50), while there is a negative correlation with AATK (r = -0.34), AATH (r = -0.18), AATA (r = -0.18). DLS is in a positive statistically significant correlation with DPLS (0.54), while DPLS is in a positive statistically significant correlation with DTL (r = 0.32) and LPS (r = 0.25). LLS is in a significant positive correlation with LPS length (r = 0.74) and in AATK (r = 0.20), AATH (r = 0.27), AATA (r = 0.29), while LPS is in a significant positive correlation with AATK (r = 0.25) and AATH (r = 0.21). AATK has a significant positive correlation with AATH (r = 0.59) and AATA (r = 0.53), and AATH has a significant positive correlation with AATA (r = 0.25). The values of the correlation coefficients vary, with the highest statistically significant positive association (r = 0.74) obtained between LLS and LPS.

**Table 5.** Pearson's correlation coefficients for kinematic parameters

| | | DTO | DLS | DPLS | DTL | LLS | LPS | AATK | AATH | AATA |
|---|---|---|---|---|---|---|---|---|---|---|
| DTO | r | 1.00 | | | | | | | | |
| | p | | | | | | | | | |
| DLS | r | .43** | 1.00 | | | | | | | |
| | p | 0.00 | | | | | | | | |
| DPLS | r | .50** | .54** | 1.00 | | | | | | |
| | p | 0.00 | 0.00 | | | | | | | |
| DTL | r | -0.07 | 0.02 | 0.32** | 1.00 | | | | | |
| | p | 0.45 | 0.85 | 0.00 | | | | | | |
| LLS | r | -0.13 | .19* | 0.09 | 0.06 | 1.00 | | | | |
| | p | 0.16 | 0.03 | 0.32 | 0.50 | | | | | |
| LPS | r | -0.13 | 0.11 | .25** | 0.17 | .74** | 1.00 | | | |
| | p | 0.15 | 0.23 | 0.01 | 0.06 | 0.00 | | | | |
| AATK | r | -34** | 0.03 | -0.05 | 0.06 | .20* | .25** | 1.00 | | |
| | p | 0.00 | 0.72 | 0.58 | 0.54 | 0.03 | 0.00 | | | |
| AATH | r | -.18* | 0.01 | -0.06 | -0.13 | .27** | .21* | .59** | 1.00 | |
| | p | 0.05 | 0.94 | 0.50 | 0.16 | 0.00 | 0.02 | 0.00 | | |
| AATA | r | -.18* | 0.03 | -0.09 | 0.00 | .29** | 0.17 | .53** | .25** | 1.00 |
| | p | 0.05 | 0.76 | 0.31 | 0.97 | 0.00 | 0.06 | 0.00 | 0.01 | |

**Legend: correlations are significant at**: *p < 0.01, **p < 0.05

By looking at the obtained results, it is determined that the kinematic parameters play a relevant role in the success of the high jump result using the scissors technique.

## DISCUSSION

Kinematic parameters with the highest variability in values are duration of take-off (SD = 39.76) and duration of the third stride (SD = 31.87), while those with the smallest variability in values are ankle angle (SD = 5.90), knee angle (SD = 8.77) and hip angle (SD = 11.91). In accordance with the obtained results, the suggestion for future research is to repeat it on a larger number of variables that would give an even better explanation of the high jump results. The large variability in the results may indicate the heterogeneity of the sample of participants in the field of motor abilities, level of motor knowledge, but also a large range in chronological age. The most stable parameter, or the result with the smallest dispersion in values, is the ankle angle (SD = 5.90). In the research by Blažević, Antekolović and Mejovšek (2006), who conducted a longitudinal study of kinematic parameters on one top jumper, the results showed that the duration of take-off is the parameter with the least variability (SD = 0.007). In the results of the descriptive analysis, in the variable DTO there is one respondent less (n = 122) compared to the other observed variables. It regards an extreme value of 532 ms (z = 6.25) which was excluded from further processing.

The results of the regression analysis showed that the predictor variables explain a significant share of the variance of 60.4% of the results of the criterion variable REZ_VIS ($F (9, 112) = 18.98$; $p < 0.001$). The variables of the penultimate stride duration, the last and penultimate stride length, and the angle in the ankle have a statistically significant influence on the height of the jump. The obtained results confirm the previous knowledge about the connection of a successful high jump with kinematic parameters in the approach and take-off phase (McGinnis, 2013). Jump height is associated with lower values of the penultimate stride duration, higher values of the last and penultimate stride length, and higher values of the ankle angle. The projection of the predictor variables on the height of the jump is explained by the fact that before the flight phase motor adaptations take place so that the jump has an optimal trajectory. When working with children, the analysis of the approach phase is done by monitoring the run-up length, run-up speed, stride length, i.e. the rhythm of the approach run, the approach angle and body position. Lower values of the penultimate stride imply a shorter duration of foot contact with the ground, i.e. a faster penultimate stride before take-off becomes the strongest factor of a successful jump ($b = - 0.43$; $p < 0.01$). The rhythmic pattern in the last two strides should be aimed at achieving an effective transformation of the horizontal and vertical components of velocity during the take-off phase (Panoutsakopoulos & Kollias, 2012) because, as Dapena and Chung (1998) suggest, a higher take-off speed generates a higher ground reaction force. In addition, the height of the jump is also influenced by the vertical velocity at the end of the take-off (Conrad & Ritzdorf, 1990), which is probably a consequence of the increase in horizontal velocity (Blažević, Antekolović, Mejovšek, 2006). According to the results of this research, it is precisely the faster penultimate stride that is important for achieving a good high jump result with the scissors technique. A higher start speed, especially when working with children, is conditioned by the level of practice of the task as well as motor skills. Precisely, too fast take-off, that is, uncontrolled take-off speed results in an inadequate transformation from the approach phase to the take-off phase and then the flight phase (Schexnayder, 1994). The horizontal velocity that is to be achieved by the end of the run should be the highest that can be controlled by the athlete, which enables the highest possible height to be jumped (Mateos-Padorno et al., 2021). Changing the speed of movement can change the perception of the entire task, therefore the repetition of motor stereotypes of movement, especially in children, is extremely important. During the analysis of kinematic parameters, the fact that they vary depending on the height of the jump should be taken into account (Blažević, Antekolović, Mejovšek, 2006). Furthermore, the results indicate that a higher HB score is associated with a higher last stride length score and a higher penultimate stride length score. According to previous research (Blažević, Antekolović, Mejovšek, 2006; IAAF, 2012), the average values of top jumpers indicate a longer penultimate stride and a shorter last stride. The same average values were confirmed by Idrizović (2010) who stated that the penultimate stride was the longest and the last stride the shortest. Dapena (2005) states that the last two strides should be performed as quickly as possible, and the increase in rhythm should be done without shortening the strides, which is in accordance with the results of this research. Thus, it can be observed that the most successful high jump results achieved by children are associated with longer last and penultimate strides. The obtained results of the regression analysis indicate that certain kinematic variables in the last three strides of the approach and take-off phase in the high jump are crucial because motor adjustments occur due to the need to effectively transform horizontal energy into a vertical jump in the take-off phase. Technical problems that may appear during take-off, and even during crossing the bar, are often caused by mistakes made in the approach phase (Mateos-Padorno, 2022). However, when comparing with other research data, it should be taken into account that the analysis was conducted on a sample of children, the children performed the scissors high jump technique, and the run was performed straight towards the bar (45°). The aforementioned facts make the research problem specific and crucial for the improvement of the technique.

In the analysis of Pearson's correlation coefficients, a statistically significant connection between individual observed variables was determined. As expected, the duration of the take-off has a statistically significant positive correlation with the duration of the last and penultimate stride, and a negative correlation with the angle in all observed joints (knee, hip, ankle). In particular, the longer the duration of the take-off, the slower the last and penultimate strides, and the smaller the angles in the knee, hip and ankle joints. In this phase, eccentric muscle contraction occurs, and it is desirable that this depreciation phase be as fast as possible for the transition from eccentric to concentric muscle contraction, which is a prerequisite for efficient transformation of horizontal to vertical velocity (Saratlija, 2020). In order to ensure sufficient kinetic energy, the foot of the take-off leg is not placed far forward, the inclination towards the back is smaller, and the angle in the knee joint of the take-off leg is smaller, which results in a shorter take-off phase (Saratlija, 2020). It is this data that indicates that the above-mentioned correlations are seen in work with children as well. The duration of the last stride is in a positive statistically significant correlation with the duration of the penultimate stride and the length of the last stride, while the duration of the penultimate stride is in a positive statistically significant correlation with the length of the stride to the bar and the length of the penultimate stride. The length of the last stride is in a significant positive correlation with the length of the penultimate stride and in all observed angles, while the length of the penultimate stride is in a significant positive correlation with the angle in the knee and hip joint in the take-off phase. The knee angle in the take-off phase has a significant positive correlation with the hip and ankle angle in the take-off phase, and the hip joint angle has a significant positive correlation with the ankle angle, both in the take-off phase. It is important to emphasize that the variable distance of the take-off leg from the landing point has a statistically significant correlation with only one variable, the duration of the penultimate stride. The take-off place is very individual and depends on the speed of the person approaching the bar, the technique of approaching the bar and the technique of crossing the bar itself (Čoh & Supej, 2008). In adult, experienced athletes, the distance between the take-off leg and the bar is between 0.90 m and 1.40 m (Dapena, 2006), while the average take-off distance in children in this study is M ± SD = 34.09 ± 17.12.

Considering that these are children between the ages of seven and twelve, it can be concluded that they have different training experience, as well as different lengths of training experience, so a suggestion for future research is to analyse the results of kinematic parameters after training interventions that would be aimed at improving the technique. In this way, training effects on technical performance would be seen. In addition, it is definitely suggested that the research be conducted on a sample that has a smaller chronological age range, because the children would be more similar in anthropometric characteristics and motor abilities. Improving the technique enables progress in the result of the high jump, but also the possibility of applying the learned knowledge in other sports and physical activities.

## CONCLUSION

The research was conducted with the aim of determining the kinematic parameters that are key to achieving the best high jump results with the scissors technique in children, as well as the mutual correlations in the approach and take-off phases. It was found that the predictors explain a significant proportion of the variance of HB, that is, a higher high jump score is associated with a lower score of penultimate stride duration, a higher score of last stride length, a higher score of penultimate strides and a higher score of ankle angle. In other words, kinematic parameters are relevant for success in the high jump. The obtained results can have a significant practical contribution in the improvement of technical performance, but also in the field of methodical approach to exercise. The development of technique is a key dimension when creating movement stereotypes, as well as in the transfer and learning of new motor skills. By improving the technique, it is possible to make progress in the result of the high jump, but also to acquire knowledge in connecting the run-up and take-off, which is also applicable in other sports.

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