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Case Report

Exploring Kinematic Variations in Clear Hip Circle to Handstand: A Case Study of Performance Styles on Uneven Bars

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Abstract: (1) Background: This case study analyzed the successful performances of female gymnasts in the finals of the 39th and 40th World Cup in Maribor (SLO). The aim was to identify variations in their execution of the Clear Hip Circle to Handstand (CHCH) on uneven bars based on kinematic parameters. (2) Methods: This study involved elite female gymnasts from the 39th (n = 5, age: 17 ± 6 months) and 40th (n = 8, age: 17.5 ± 6 months) World Cups, totaling 13 gymnasts. Kinematic analysis was performed on 15 successful routines using the Ariel Performance Analysis System (Ariel Dynamics Inc., San Diego, CA). The analysis focused on 16 anthropometric reference points and 8 body segments, including the body mass center of gravity (CG). The main reference points analyzed were the hip joint, the shoulder joint, and the CG along the xy-axes. Trajectory, velocity, angle, and angular velocity of the hips and shoulders were calculated. Pearson correlation analysis was employed to assess the relationships between the kinematic variables. (3) Results: High intercorrelations between the reference points along the xy-axes (0.81–0.99) and optimal movement velocity were found. Dispersed results were observed for kinematic parameters of angle (0.10–0.16) and angular velocity of the hip joints (0.60–1.00), with similar dispersions for shoulder joints (0.51–1.00). Three distinct techniques were identified: (1) stretched body with minimal hip joint flexion throughout; (2) extended body with a short, quick hip joint extension during shoulder movement; and (3) hyperextension in the hip joint. (4) Conclusions: The kinematic analysis revealed three different performance styles of the CHCH among finalists. These variations in technique do not affect the success of the performance. This research contributes to a better understanding of the technique but does not prefer one style over another.

Keywords: female gymnasts; kinematics; uneven bars; analysis; World Cup series

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1. Introduction

George was the first to propose an ideal model for performing the Clear Hip Circle to Handstand (CHCH) on uneven bars, which suggested a three-phase technique [1].

Later studies confirmed a four-phase model for the CHCH, with each phase involving different kinematic parameters. These phases have been observed on both parallel and uneven bars [2–4].

Prassas [5] systematized all the biomechanical studies that have been conducted in men's and women's artistic gymnastics.

Hiley [6] emphasized that performance improvement in gymnastics should focus on optimizing outcomes, which requires minimizing the effort of joint torque, a key factor for scoring and performance.

The evaluation of gymnastics performance is increasingly objectified through biomechanical criteria, which play a central role in analyzing and optimizing gymnastics techniques.

Veličković and associates [3,7] proposed a five-stage method for defining complex gymnastics skills. This approach contrasts with simpler techniques that require less information for training.

Suchilin [8] identified that the technical structure of gymnastics elements operates on three levels: periods, stages, and phases. These levels help divide complex gymnastics elements into manageable parts based on both pedagogical and biomechanical criteria.

Biomechanical criteria are used to explain how analyzed parameters behave during actual performances. Kinematic analysis has become the dominant method for explaining movement techniques in artistic gymnastics, helping to simplify and make gymnastics movements more accessible for analysis and improvement.

Numerous researchers have focused on kinematic analysis to determine the efficiency of movement execution, to avoid mistakes during performances, and to increase success in performance techniques [4,9–12].

The technique for performing elements on bars, such as uneven bars, has been extensively analyzed [13–16].

Movements on uneven bars primarily occur in the sagittal plane, such as the giant swing, where the horizontal bar serves as the axis. Rotational movements occur in the transverse plane, where the axis runs through the gymnast's body [17].

Gymnasts performing the CHCH exhibit high angular velocity during movements, particularly during transitions such as shoulder flexion when transitioning into a handstand in the upward phase [18].

Alekperov [19] proposed an optimal model for performing CHCH on parallel bars, stating that the body mass center of gravity (CG) should reach specific heights and the gymnast should have an initial flight velocity of 3 m/s for a successful performance.

A rare analysis of body segment trajectories highlighted key elements of the clear hip circle, including the launch posture from a handstand, horizontal momentum during descent between the shoulders and toes, and the transition from hanging to handstand [20].

Despite the fundamental importance of the CHCH skill in both junior and senior competitions, there has been insufficient research focusing on this element. The existing literature lacks coverage of how variations in kinematics, such as the center of gravity movement and angular velocity of the hips and shoulders, can still lead to successful outcomes.

This study is a pioneer in its detailed analysis of kinematic parameters in CHCH performances at an elite level, offering new insights previously unexplored in the existing literature.

The main aim of the research is to identify differences in CHCH performances on uneven bars based on kinematic parameters, contributing to a better understanding of variations in technique and how they influence performance success.

We hypothesized that there are significant correlations in the trajectory, peripheral movement velocities, angles, and angular velocities of each parameter that can help determine whether specific kinematic differences are related to variations in the CHCH technique.

2. Materials and Methods

This research is a case study of the successful CHCH performances of elite female gymnasts, with data recorded live during the uneven bars' finals.

2.1. Participants

The research sample consisted of 13 female gymnasts, each with a minimum of 8–10 years of competitive experience, who participated in the finals of the 39th and 40th World Cups in Maribor (SLO), performing 15 CHCH elements.

The sample of subjects at the 39th World Cup (n = 5; mean age: 17 ± 6 months) performing 5 CHCH on uneven bars consisted of S.M. representing Austria, T.E. from Croatia, L.G. from Hungary, N.P. from the Czech Republic, and N.Pa. from the Slovak Republic.

The sample of subjects at the 40th World Cup (n = 8; mean age: 17.5 ± 6 months) performing 10 CHCH on uneven bars consisted of B.H. from the People's Republic of China, C.B. from France, M.R. from Great Britain, V.M. from Greece, T.D. from Croatia, S.T. from Nederland, S.G. from Slovenia, and A.U. from Finland.

While all gymnasts performed one CHCH on uneven bars, gymnasts from China and Finland performed two CHCHs in their gymnastic routines.

The correlation matrix and the athletes' deviation from the starting position were used as criteria to divide them into three groups.

The study was conducted in accordance with the Declaration of Helsinki and Recommendations for Scientific Research Involving Human Subjects and approved by the Institutional Review Board of the University of Niš (approval number 8/19-01-007/07-016).

A consent form was developed to obtain approvals from gymnasts and their parents/guardians, as well as to inform them about their rights, the purpose of the data collection, and the methods used for processing the information. All participants and their parents/guardians agreed to participate in this research and signed informed consent forms.

2.2. Variables

Kinematic parameter sample:

1. Foot trajectory along the xy-axes [m];
2. Shoulder trajectory along the xy-axes [m];
3. Head trajectory along the xy-axes [m];
4. CG trajectory along the xy-axes [m];
5. CG velocity along the xy-axes [m/s];
6. Shoulder velocity along the xy-axes [m/s];
7. Hip velocity along the xy-axes [m/s];
8. Shoulder angular velocity [deg/s];
9. Hip angular velocity [deg/s].

Goniometric parameter sample:

1. Hip joint angle along the xy-axes [deg];
2. Shoulder joint angle along the xy-axes [deg].

2.3. Instruments

This research comprised a kinematic methodology and anthropometric model of the human body consisting of 15 body segments, and 16 anthropometric reference points calculated by Susanka [21]. An absolute spatial reference system, as presented by Winter [22], was utilized, and the CG was calculated using this model. The movements on uneven bars are two-dimensional and are performed in the sagittal plane (xy-plane). Any movement along the *z*-axis is considered a deviation from the established technique or an error in performing the analyzed exercises. Since these *z*-axis displacements are minimal, they were ignored and not considered for further analysis, as correct execution of the technique should not involve *z*-axis movement. Given that this is a symmetrical two-dimensional movement, only the points and segments on the right side of the gymnast's body were

analyzed, since body movement speeds are the same on both sides, and the side closer to the camera lenses was prioritized for exercise analysis.

After selecting the recorded material (without technical errors), further data processing was carried out through the following stages:

(a) Extracting positions (frame grabbing)—As the execution of the two exercises selected for analysis takes 2–3 s, 50–100 frames were extracted for each execution.

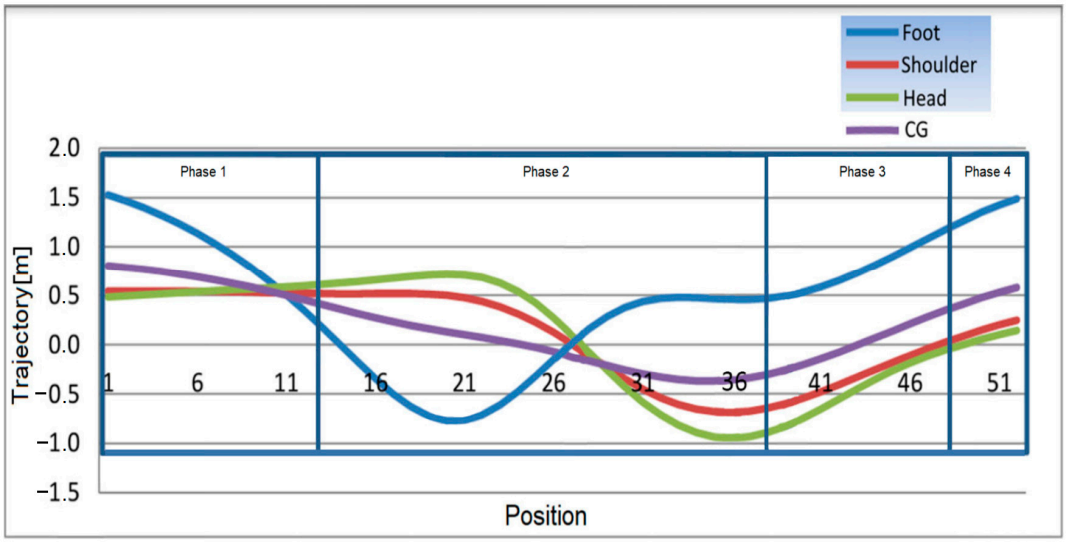
(b) Image digitization—Analog signals were converted to digital using a digitizer connected to a computer.

(c) Creating a kinogram—Defining the desired configuration for each gymnast and each position of the selected movement was performed using a fifteen-segment measurement model, with 16 anthropometric points and 1 point representing the body's center of gravity. The verification of anatomical positions and reference points and segments was achieved electronically by the same measurer (E.P.). The advantage of the APAS program is that it is a non-invasive method for athletes, meaning it does not require the placement of any markers on the skin of the subjects. The edges of the apparatus, i.e., in this case, the edges of the upper and lower parts, were also marked with four points. The APAS program enabled the video camera to record the desired movement in the field previously measured for the given measurement and numerically determined the movement of all body parts or the body as a whole. By projecting each frame of the video onto the monitor and locating the pointer, each position of the plotted reference point was assigned a numerical value from the selected coordinate system. Kinograms were created using stick figures, which represent simplified models of the human body and provide a minimalistic visual representation of the gymnasts' motion.

(d) Transformation of two-dimensional data into three-dimensional data—This step was possible because the recording was carried out with two video cameras. To harmonize the images from both cameras, an internal synchronizer was used, which digitized an adequate number of reference points.

2.4. Optimal Technique Model for the CHCH on Uneven Bars

The optimal technique model for the CHCH on uneven bars includes four phases (Figure 1): (1) Control Gravity Phase; (2) Gravitational Phase; (3) Lower Vertical Passing; and (4) Swing to Handstand Position [23].



Legend: Phase 1-Control Gravity Phase; Phase 2-Gravitational Phase; Phase 3-Lower Vertical Passing; and Phase 4-Swing to Handstand Position.

Figure 1. Movement trajectory of the referent points from the xy-axes for CHCH. CG-body mass center of gravity.

At the beginning of the movement, there is a short period of accelerated retroflexion in the shoulder joint (mainly until the moment when the legs and body are slightly above the horizontal position), likely to initiate acceleration for the entire movement. This is followed by a period of uniform-velocity retroflexion (hypothetically controlled by the eccentric contraction of the shoulder muscles) until the shoulder exits the support surface, at which point a slow and controlled retroflexion is detected. At this stage of the movement, the body is almost fully extended at the hip joints, and the angular velocity is close to zero, with angle values slightly below 180° on average.

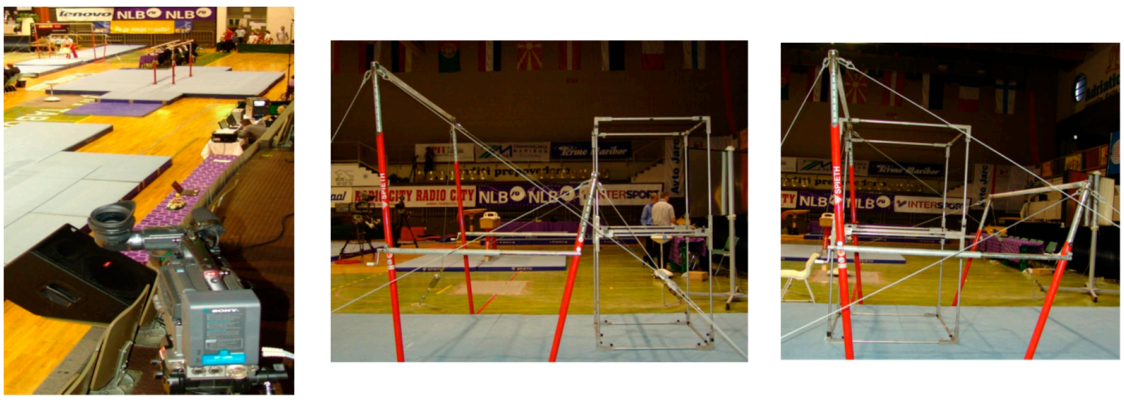
2.5. Data Processing

The mean values of the CG (trajectory and velocity), hip joint (angle, velocity, and angular velocity), and shoulder joint (trajectory, velocity, and angular velocity) along the xy-axes during the execution of the CHCH were determined using kinematic methods in accordance with the standards of the Ariel Performance Analysis System (APAS). The APAS analyzes reference points across several phases. Female gymnasts were recorded during the competition using two SONY DVCAM DSR-300PK digital cameras, positioned on the left and right sides of the apparatus at a right angle (90°) relative to the axis, which was perpendicular to the direction of the gymnasts' movement and passed through the middle of the apparatus (between the lower and higher bar) and the point of grip—the axis of rotation. The camera frequency was set to 50 Hz, as performed by [24,25], while the resolution was 720 × 576 pixels. The cameras were synchronized using an internal synchronous system.

It was necessary to bring the participants' different starting positions to the same level, i.e., the same initial position, so that the APAS program could process the moderate space. The desired moderate space was adjusted so that all movements would be used as a reference against the first gymnast, representing absolute space. S.M. from Austria was used as the baseline for absolute zero in terms of height and length, and all other performances on the uneven bars were aligned within her reference space.

In the starting position, the contestants should be facing the same direction so that the statistics (angle, speed, acceleration, angular velocity) can be recorded in the same coordinate system.

The camera angles were selected based on the expertise of the Institute of Sports, Faculty of Sports, University of Ljubljana. The chosen recording angles revealed errors in plotting the coordinates along the "x" and "y" axes, as well as minor displacements along the "z" axis, although all exercises were successfully performed. Prior to recording, and for the purpose of accurate calibration of the measurement space, three reference frames—cubes (2 × 1 m^3)—were positioned and leveled on the abutments of the uneven bars. Two cubes were placed one above the other in front of and behind the lower bar (Figure 2b), while the third was positioned in front of the higher bar (Figure 2c).



(**a**) (**b**) (**c**)

Figure 2. Space moderation under the angle of 90° (**a**); of the low bar (**b**); and of the high bar (**c**).

The conversion of video footage into quantitative data and the calculation of kinematic parameters for this research were conducted in accordance with the standards of the APAS. The APAS comprises two functionally interconnected units: a video camera (for signal collection) and a digitizer connected to a computer (for data acquisition).

The criterion variable used to standardize all derived CHCHs was the exercise performed by S.M. (AUT) at the 39th World Cup, which served as the baseline for absolute zero height and length for all other CHCH performances on the uneven bars. The different starting positions of the competitors were standardized to the same initial position, allowing the APAS to process the data consistently.

It was necessary to align the different starting positions of the participants to a common level, or the same initial position, for the APAS program to process the movement area effectively. The reference area was adjusted to mirror the first gymnast's performance, which served as the baseline. All subsequent performances on the uneven bars were aligned to fit within this baseline. Each routine was rotated and adjusted so that the center corresponded with the axis of rotation.

Calculated kinematic parameters were further prepared for statistical analysis.

Pearson's correlation was used to measure the strength and direction of the linear relationship between the performance variables of different gymnasts.

SPSS software (SPSS version 24.0, SPSS Inc., Chicago, IL, USA) was used for statistical analysis. A p value at the level of 0.05 was considered significant.

3. Results

Based on the analysis of the CG, gymnast B.H. (CHN) was selected as the reference, as her movements showed a strong correlation with those of the other gymnasts. After creating the canonical correlation matrix, it was determined that B.H.'s CHCH performance technique had approximately 99% correlation with the performance techniques of the other gymnasts. Her kinogram was therefore used as the representative kinogram in the description of the movement technique.

According to the model, the execution of this element takes 1.1 s, with 52 positions analyzed for each gymnast. The starting positions of the gymnasts were normalized to a single point.

The analysis of Figure 3 along with the obtained correlation (see Appendix A, Tables A1 and A2) confirms a high correspondence in the trajectory and velocity of the CG among all female competitors. All correlation coefficients are very high and statistically significant.

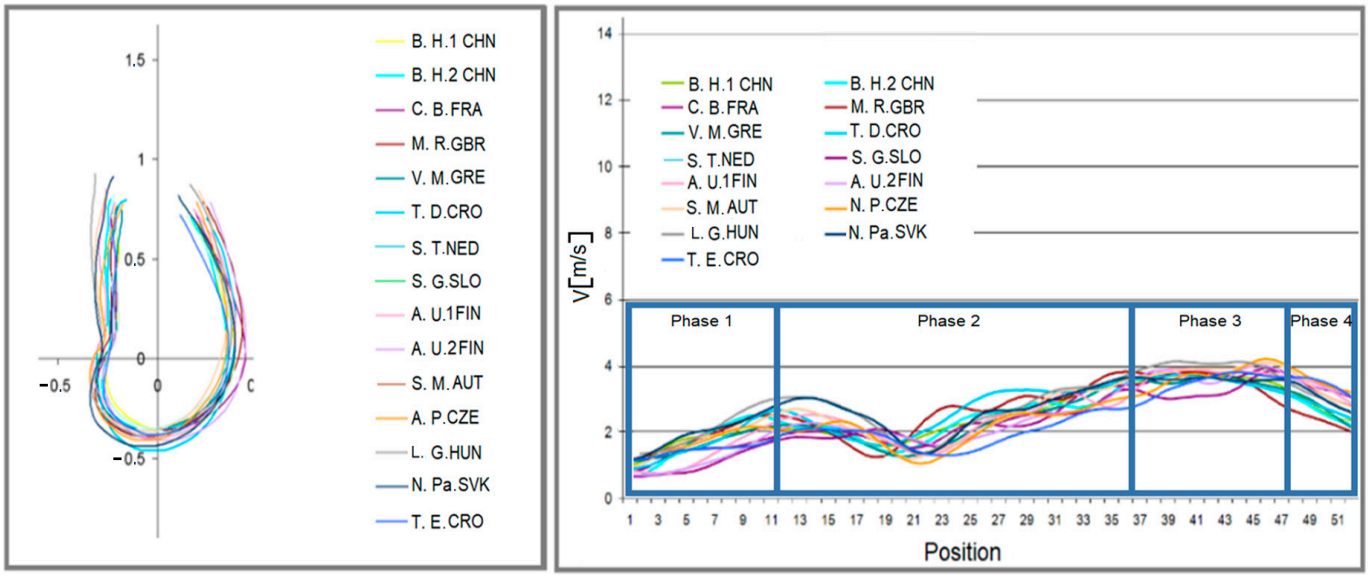
The analysis of Figure 4 along with the phases' correlation coefficients for the trajectory of the shoulder joint and its velocity (see Appendix A, Tables A3 and A4) confirm a high level of correspondence in both reference points. All correlation coefficients for the shoulder joint's trajectory along the xy-axes and its velocity are very high and statistically significant (>0.82 for both kinematic parameters).

The analysis of Figure 5 along with the phases' correlation coefficients for the hip joint angle (see Appendix A, Table A5) and its angular velocity (see Appendix A, Table A6) show that although there are different styles of performing this exercise, their intercorrelation is high.

A basic indicator for the distribution of results for one parameter is the arithmetic mean. Expert analysis uses this measure of central tendency, which represents the best measure of the basic quantitative characteristics of one parameter.

Figure 6 represents the arithmetic means of the angles in the hip and shoulder joints (left) and angular velocities in the same joints (right).

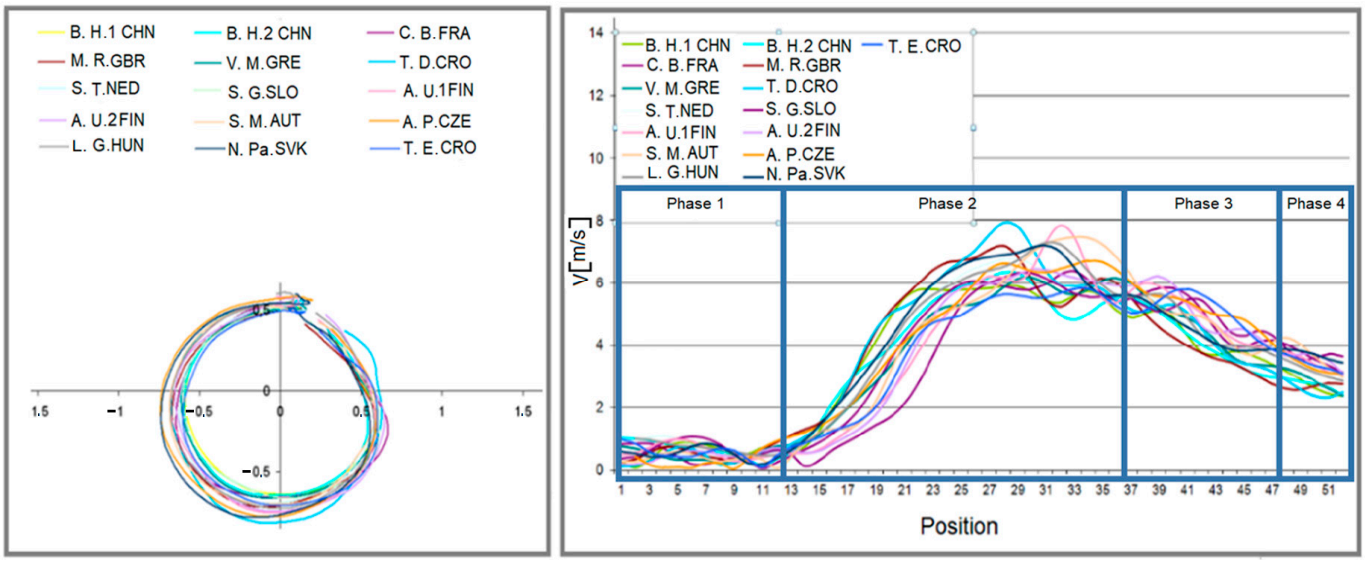
Figure 7 (a,b,c) represents the hip joint angles with Stick Figures 1–3 indicate different techniques/styles in Phase 1 of the CHCH (red rectangle).



Legend: Phase 1—Control Gravity Phase; Phase 2—Gravitational Phase; Phase 3—Lower Vertical Passing; and Phase 4—Swing to Handstand Position.

(**a**) (**b**)

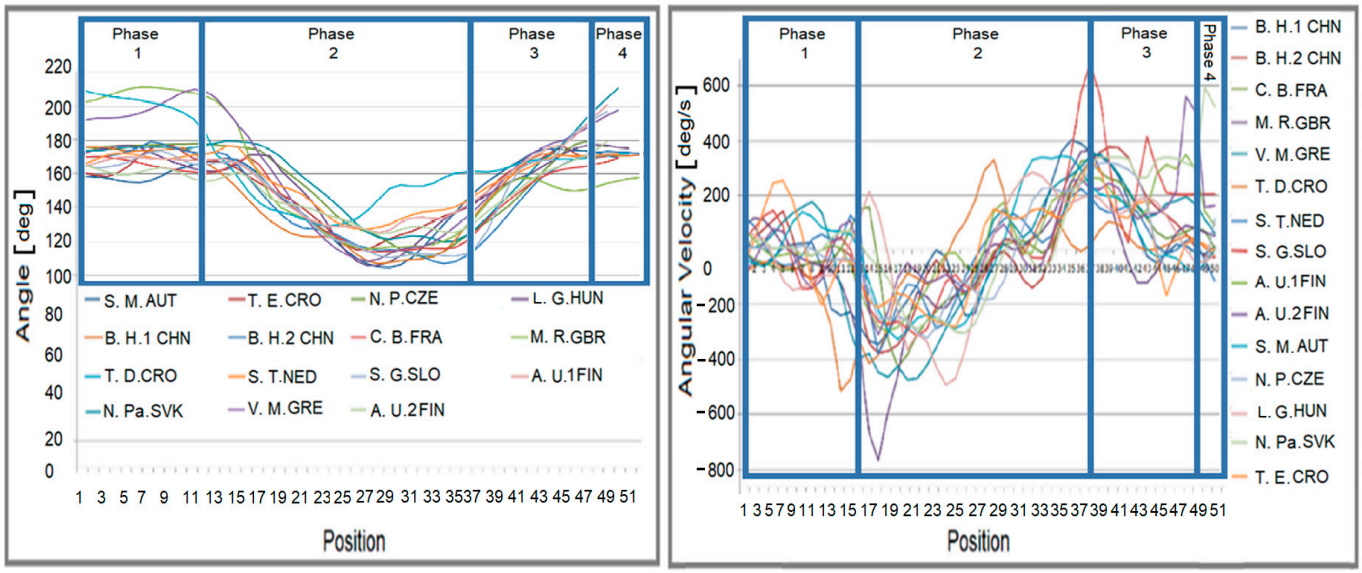
Figure 3. Trajectory [m] (**a**) and velocity [m/s] (**b**) of the CG during CHCH along the xy-axes.



Legend: Phase 1—Control Gravity Phase; Phase 2—Gravitational Phase; Phase 3—Lower Vertical Passing; and Phase 4—Swing to Handstand Position.

(**a**) (**b**)

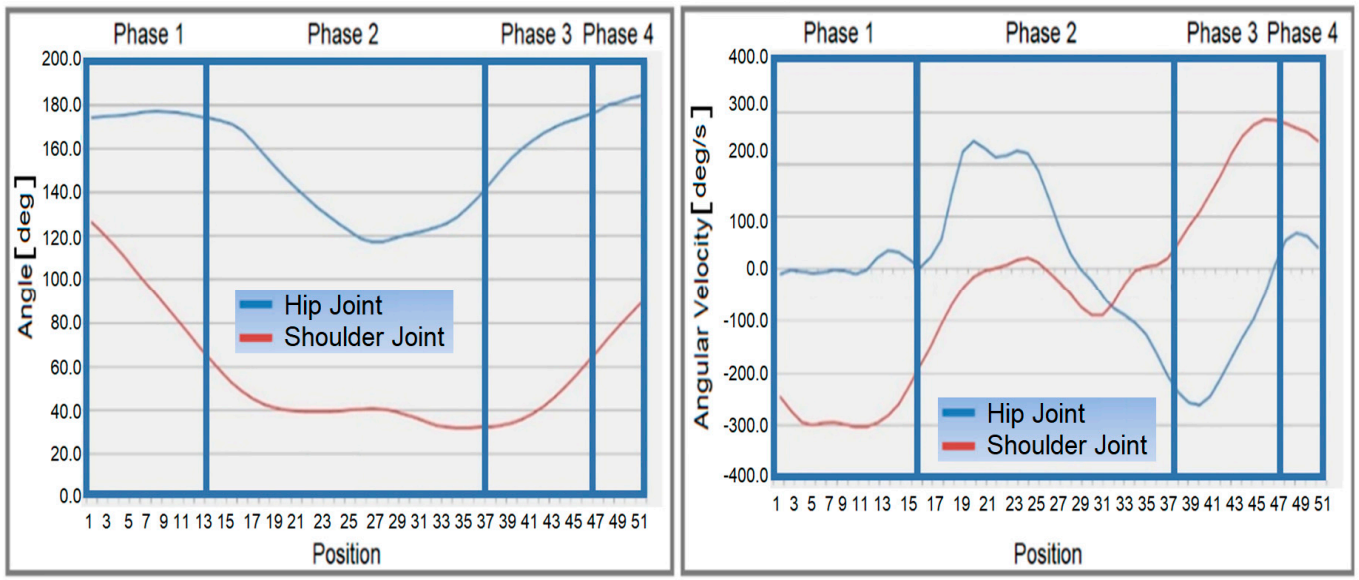
Figure 4. Trajectory [m] (**a**) and velocity [m/s] (**b**) of the shoulder joint during CHCH along the xy-axes.



Legend: Phase 1—Control Gravity Phase; Phase 2—Gravitational Phase; Phase 3—Lower Vertical Passing; and Phase 4—Swing to Handstand Position.

(**a**) (**b**)

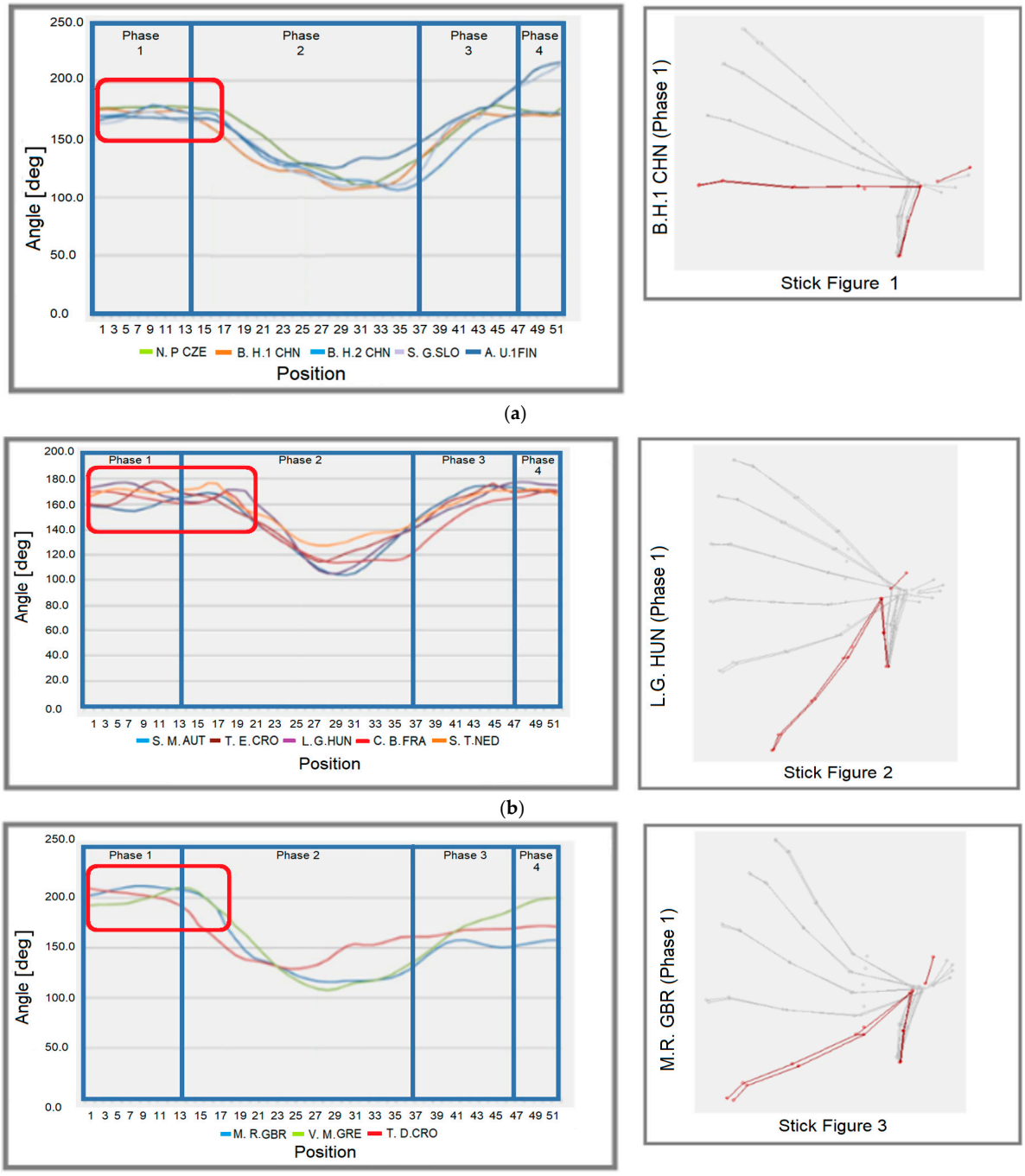
Figure 5. Angle [deg] (**a**) and angular velocity [deg/s] (**b**) of the hip joint during CHCH along the xy-axes.



Legend: Phase 1—Control Gravity Phase; Phase 2—Gravitational Phase; Phase 3—Lower Vertical Passing; and Phase 4—Swing to Handstand Position.

(**a**) (**b**)

Figure 6. The arithmetic means of the hip joint (blue line) and shoulder joint (red line) angles [deg] (**a**) and angular velocity [deg/s] (**b**) along the xy-axes.



Legend: Phase 1—Control Gravity Phase; Phase 2—Gravitational Phase; Phase 3—Lower Vertical Passing; and Phase 4—Swing to Handstand Position.

Figure 7. The angles [deg] of the hip joint with stick figures along the xy-axes and red boxes indicating different techniques/styles in Phase 1 of the CHCH.

4. Discussion

This biomechanical study aimed to determine differences in the CHCH performances on uneven bars based on kinematic parameters.

Data in Table A1 reflect that, despite some individual variability, most gymnasts in the dataset perform with a high degree of uniformity in the vertical movement of their CG, likely due to shared techniques and biomechanical characteristics.

Table A2 reveals high levels of similarity in CG velocity among many gymnasts, particularly between V.M., S.T., and S.M., suggesting uniformity in their movement execution.

Gymnasts like S.G. and T.E., on the other hand, demonstrate somewhat more distinct CG velocity patterns, indicating potential variations in technique or physical characteristics.

Data in Tables A3 and A4 show overwhelmingly strong correlations in shoulder joint trajectory (most correlation values are close to or equal to 1.00, indicating nearly identical movement patterns for many participants) and velocity among the gymnasts (particularly with S.T., V.M., B.H., and N.P., whose correlations frequently approach or reach near-perfect levels).

The minimum values of the correlation coefficients for the movement trajectory are 0.82., and for the velocity of the shoulder joint, the value is 0.82 as well (both for S.G./M.R.), indicating that for the successful execution of the CHCH technique, the shoulder joint's movement remains exclusively horizontal from the beginning of the movement to the end of Phase 1 (there is no change in the xy-axes value). The alignment of the shoulder joint's trajectory with the CG occurs when the shoulders finish moving forward, with the mean value of the matched trajectories occurring at the 11th position, registering a value of 0.509 m. This indicates a high degree of uniformity in how these athletes execute shoulder joint trajectory and velocity during the movement.

Data in Tables A5 and A6 indicate that the hip joint angle of several gymnasts, such as N.P., C.B., V.M., T.E., and S.T., or hip joint angular velocity, such as B.H., V.M., N.P., and M.R., show consistently high correlations with each other, which indicates that these athletes perform the movement in a very similar manner.

However, those with lower correlations presented in Table A5 (such as 0.44, 0.52, 0.54, 0.55, 0.58, 0.59) may have a more unique approach to the movement, i.e., the same movement pattern is observed when transitioning from Phase 1 to Phase 2 of the technique.

Some gymnasts (e.g., T.D.) display more individualized techniques. This variability could reflect differences in their training approaches, physical attributes, or execution of the movement. Four low correlation coefficients that are not statistically significant were detected (Table A6), specifically between gymnasts T.D. and C.B. (0.16), S.M. and T.D. (0.20), L.G. and T.D. (0.11), and N.Pa. and T.D. (0.10). The low correlation coefficients of the hip joint angular velocity, and the lack of statistical significance with other gymnasts can be explained as follows:

(1) T.D. (CRO) is one of the few gymnasts who enters the turn with significant hyperextension;
(2) The values of hip joint flexion are significantly higher compared to the other gymnasts (she performs the full circle with an extended body) throughout the entire movement;
(3) The maximum angular velocity of flexion is achieved earlier compared to the other gymnasts;
(4) Maximum flexion is achieved earlier compared to the other gymnasts (while the shoulder points are still in the Control Gravity Phase—first quadrant);
(5) Extension begins sooner and the maximum angular velocity of extension is achieved earlier compared to the other gymnasts (in the first part of the second quadrant—shoulder joint).

Low correlation coefficients of angular velocities may also suggest a different performance style or a different model for transitioning from Phase 1 to Phase 2 of the performance technique. This indicates that these four gymnasts follow a different model (or style) of movement when entering the second phase of the CHCH performance technique.

Based on the different angles observed in the first phase of the CHCH performance technique, it can be concluded that there are three distinct ways in which the finalists on the uneven bars initiate the CHCH (Figure 7):

(a) The technique is performed with a stretched body and a slightly pronounced flexion in the hip joint throughout the entire execution of Phase 1, as shown in Stick Figure 1 (four female competitors: B.H., N.P., S.G., and A.U.). In the first part of the movement, the body is almost fully extended in the hip joints (the angular velocity is close to zero, with the angle values averaging slightly below 180 degrees).
(b) With a stretched body, but at the moment when the shoulders begin the backward movement, a short and quick extension is noted in the hip joint, the so-called "Courbet"

(this refers to an extension in the hip joint with peripheral support, where the legs appear to stand while the hips drop down, as shown in Stick Figure 2. This movement is observed in six competitors: S.M., T.E., L.G., N.Pa., C.B., and S.T.).

(c) Hyperextension in the hip joint as shown in Stick Figure 3 is determined in three competitors (M.R., T.D., and V.M.).

Generally, the results revealed high correlations across kinematic variables, with most correlations ranging from 0.81 to 1.00, indicating consistent execution patterns among gymnasts.

Variations in angular and angular velocity parameters, especially for the hips and shoulders, indicate the presence of different technical approaches. However, these variations do not seem to impact overall performance success.

Despite individual stylistic differences, elite gymnasts maintain a high level of technical consistency in performing the CHCH.

Techniques can be categorized into different styles, general or specific, influencing the selection process. Technique selection is driven by skill requirements and the performer's physical characteristics [26].

Each gymnast incorporates personal style into their performance, deviating to varying extents from the ideal model. A gymnast's specific style depends on factors such as anthropometric characteristics and velocity/muscular properties.

A gymnast's unique style is a defining aspect of their overall gymnastics' skill.

Motor control and synchronization are crucial for learning gymnastics skills [27], where practice is the most important factor in skill effectiveness [28].

However, a biomechanical analysis of movement must be complemented with muscle activation analysis at each stage of the CHCH, to avoid forming incorrect movement technique patterns during the training process when learning a new exercise.

Once adopted, motor performance can evolve into an individual style, while the ideal model for performing gymnastics skills remains consistent.

Our kinematic analysis of movement technique leads to an optimized training process, allowing for skill mastery in a shorter period of time. Successfully mastering the technique means that the motor action becomes automatized as stated in [29], reducing the need for excess energy expenditure during the movement.

Hence, top-level gymnasts must have exceptional physical and technical preparation, which varies according to their individual characteristics. Flexibility and strength are two critical abilities that cannot be neglected in the training process [30], and for elite gymnasts, they must be trained at maximum intensity.

Regarding anthropometric characteristics, a gymnast's height and weight significantly affect the learning of new skills on the uneven bars [31]. The CHCH, a rotational-type skill, is influenced by height and body mass, which affect the rotational speed of the movement.

Variations in the technique of performing the CHCH between taller and shorter gymnasts are reflected in the speed of rotation, and the flexibility and strength of the shoulder can contribute to easier and faster execution of the CHCH movement. The ratio of arm and shoulder strength, flexibility of the pelvic and shoulder joints, and the gymnast's height-to-weight index are all correlated with the successful performance of the CHCH.

Further research in this area is necessary to better understand these relationships.

While our study provides valuable insights into the kinematic patterns and technical variations of elite gymnasts performing the CHCH at the 39th and 40th World Cup, its limitations include the small and specific sample, the focus on successful performances, and the narrow emphasis on kinematic factors.

At present, generalizing the results is not feasible, as the CHCH is now considered a basic element of the uneven bars and is included in age-group competition programs. Since the current philosophy for every top-level gymnast is to maximize their difficulty value in competitions, we propose that this type of study can be repeated with younger gymnasts at international competitions such as the Balkan Championship, Horizon Cup, and Mediterranean Championship.

Future research should explain the variability of selected kinematic parameters and changes in the second and third phases of movement, expand on these findings by including a larger sample size, incorporate additional biomechanical variables, and consider longitudinal performance data, as well.

5. Conclusions

The gymnasts exhibited a high level of technical consistency in their movement patterns, especially in key areas such as hip joint and shoulder joint kinematics, and CG movement. Strong correlations among the participants (e.g., B.H. 1, B.H. 2, M.R., and L.G.) imply that standardized techniques are being used and executed with precision, which is critical in a sport like gymnastics where biomechanical consistency often correlates with performance success.

Gymnast S.G. from Slovenia showed a lower correlation with the CHCH technique of the other gymnasts, which suggests natural variation due to individual differences in body mechanics, skill level, or personal execution styles. However, overall patterns still indicate a high degree of uniformity in movement execution.

The minimum values of the correlation coefficients for the movement trajectory and shoulder joint velocity are both 0.82 (for S.G./M.R.), indicating that from the beginning of the movement to the end of Phase 1, the shoulder joint exhibits minimal movement. Depending on anthropometric parameters and movement speed entering Phase 2, the gymnasts initiate rotation by quickly moving their shoulders back during this phase.

Minimal correlations do not necessarily indicate a violation of the movement technique but rather that each gymnast begins the movement in her own way. It is important to consider the elements that precede and follow the CHCH, as the difficulty values of those elements and their combinations impact how each gymnast starts the CHCH movement.

The successful implementation of the CHCH on uneven bars does not depend solely on the first phase or the gymnast's entry into the Gravitational Phase but rather on establishing rotational movement on the bar.

The kinematic analysis revealed three different performance styles of the CHCH among finalists. These variations in technique do not affect the success of the performance. This research contributes to a better understanding of the technique but does not prefer one style over another.

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Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors upon request.

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Appendix A

Table A1. Correlations of the CG trajectory.

	B.H. 1	B.H. 2	C.B.	M.R.	V.M.	T.D.	S.T.	S.G.	A.U. 1	A.U. 2	S.M.	T.E.	N.P.	L.G.	N.Pa.
B.H. 1	**1.00**														
B.H. 2	**1.00**	**1.00**													
C.B.	**0.97**	**0.98**	**1.00**												
M.R.	**0.99**	**0.99**	**0.94**	**1.00**											
V.M.	**0.99**	**0.99**	**1.00**	**0.97**	**1.00**										
T.D.	**0.98**	**0.99**	**0.99**	**0.97**	**1.00**	**1.00**									
S.T.	**0.99**	**1.00**	**0.99**	**0.98**	**1.00**	**1.00**	**1.00**								
S.G.	**0.86**	**0.90**	**0.96**	**0.81**	**0.93**	**0.93**	**0.91**	**1.00**							
A.U. 1	**0.91**	**0.93**	**0.98**	**0.86**	**0.96**	**0.96**	**0.95**	**0.99**	**1.00**						
A.U. 2	**0.88**	**0.91**	**0.97**	**0.84**	**0.95**	**0.95**	**0.93**	**1.00**	**1.00**	**1.00**					
S.M.	**0.98**	**0.99**	**1.00**	**0.96**	**1.00**	**0.99**	**0.99**	**0.94**	**0.97**	**0.95**	**1.00**				
T.E.	**0.92**	**0.95**	**0.99**	**0.88**	**0.97**	**0.97**	**0.96**	**0.99**	**1.00**	**0.99**	**0.98**	**1.00**			
N.P.	**0.98**	**0.99**	**1.00**	**0.95**	**1.00**	**0.99**	**0.99**	**0.95**	**0.97**	**0.96**	**1.00**	**0.98**	**1.00**		
L.G.	**0.99**	**0.99**	**0.94**	**1.00**	**0.97**	**0.96**	**0.98**	**0.81**	**0.87**	**0.84**	**0.96**	**0.89**	**0.95**	**1.00**	
N.Pa.	**0.97**	**0.99**	**0.99**	**0.95**	**0.99**	**0.99**	**0.99**	**0.95**	**0.97**	**0.96**	**0.99**	**0.98**	**0.99**	**0.95**	**1.00**

Legend: bolded correlations are significant at $p < 0.05$ (N = 52).

Table A2. Correlations of the CG velocity.

	B.H. 1	B.H. 2	C.B.	M.R.	V.M.	T.D.	S.T.	S.G.	A.U. 1	A.U. 2	S.M.	T.E.	N.P.	L.G.	N.Pa
B.H. 1	**1.00**														
B.H. 2	**0.96**	**1.00**													
C.B.	**0.97**	**0.91**	**1.00**												
M.R.	**0.93**	**0.93**	**0.83**	**1.00**											
V.M.	**0.98**	**0.96**	**0.96**	**0.90**	**1.00**										
T.D.	**0.93**	**0.96**	**0.88**	**0.95**	**0.93**	**1.00**									
S.T.	**0.95**	**0.98**	**0.90**	**0.93**	**0.97**	**0.95**	**1.00**								
S.G.	**0.87**	**0.83**	**0.94**	0.72	**0.88**	**0.84**	**0.81**	**1.00**							
A.U. 1	**0.91**	**0.91**	**0.95**	0.78	**0.94**	**0.88**	**0.91**	**0.93**	**1.00**						
A.U. 2	**0.91**	**0.87**	**0.96**	0.76	**0.92**	**0.84**	**0.86**	**0.97**	**0.97**	**1.00**					
S.M.	**0.95**	**0.93**	**0.95**	**0.82**	**0.97**	**0.87**	**0.94**	**0.89**	**0.96**	**0.94**	**1.00**				
T.E.	**0.85**	0.78	**0.93**	0.63	**0.87**	0.71	0.78	**0.91**	**0.93**	**0.94**	**0.92**	**1.00**			
N.P.	**0.92**	**0.89**	**0.95**	0.77	**0.94**	**0.82**	**0.90**	**0.88**	**0.93**	**0.91**	**0.96**	**0.93**	**1.00**		
L.G.	**0.93**	**0.96**	**0.87**	**0.90**	**0.96**	**0.90**	**0.98**	0.76	**0.89**	**0.84**	**0.94**	0.77	**0.88**	**1.00**	
N.Pa.	**0.90**	**0.91**	**0.91**	0.79	**0.95**	**0.86**	**0.94**	**0.86**	**0.94**	**0.90**	**0.97**	**0.85**	**0.90**	**0.95**	**1.00**

Legend: bolded correlations are significant at $p < 0.05$ (N = 52).

Table A3. Correlations of the shoulder joint trajectory.

	B.H. 1	B.H. 2	C.B.	M.R.	V.M.	T.D.	S.T.	S.G.	A.U. 1	A.U. 2	S.M.	T.E.	N.P.	L.G.	N.Pa.
B.H. 1	**1.00**														
B.H. 2	**1.00**	**1.00**													
C.B.	**0.96**	**0.98**	**1.00**												
M.R.	**1.00**	**0.99**	**0.95**	**1.00**											
V.M.	**0.96**	**0.98**	**1.00**	**0.95**	**1.00**										
T.D.	**0.99**	**1.00**	**0.99**	**0.99**	**0.99**	**1.00**									
S.T.	**0.98**	**0.99**	**0.99**	**0.97**	**0.99**	**1.00**	**1.00**								
S.G.	**0.84**	**0.88**	**0.96**	**0.82**	**0.95**	**0.90**	**0.92**	**1.00**							
A.U. 1	**0.89**	**0.92**	**0.98**	**0.87**	**0.98**	**0.94**	**0.95**	**0.99**	**1.00**						
A.U. 2	**0.88**	**0.92**	**0.98**	**0.87**	**0.98**	**0.94**	**0.95**	**1.00**	**1.00**	**1.00**					
S.M.	**0.93**	**0.96**	**0.99**	**0.91**	**0.99**	**0.97**	**0.98**	**0.97**	**0.99**	**0.98**	**1.00**				
T.E.	**0.90**	**0.93**	**0.99**	**0.89**	**0.98**	**0.95**	**0.96**	**0.99**	**1.00**	**1.00**	**0.99**	**1.00**			
N.P.	**0.95**	**0.97**	**1.00**	**0.94**	**1.00**	**0.98**	**0.99**	**0.97**	**0.99**	**0.99**	**0.99**	**0.99**	**1.00**		
L.G.	**1.00**	**1.00**	**0.96**	**1.00**	**0.96**	**0.99**	**0.98**	**0.84**	**0.89**	**0.88**	**0.93**	**0.90**	**0.95**	**1.00**	
N.Pa.	**0.95**	**0.97**	**1.00**	**0.94**	**1.00**	**0.98**	**0.99**	**0.96**	**0.99**	**0.98**	**0.99**	**0.99**	**1.00**	**0.95**	**1.00**

Legend: bolded correlations are significant at $p < 0.05$ (N = 52).

Table A4. Correlations of the shoulder joint velocity.

	B.H. 1	**B.H. 2**	**C.B.**	**M.R.**	**V.M.**	**T.D.**	**S.T.**	**S.G.**	**A.U. 1**	**A.U. 2**	**S.M.**	**T.E.**	**N.P.**	**L.G.**	**N.Pa.**
B.H. 1	**1.00**														
B.H. 2	**0.98**	**1.00**													
C.B.	**0.95**	**0.96**	**1.00**												
M.R.	**0.98**	**0.98**	**0.92**	**1.00**											
V.M.	**0.96**	**0.98**	**0.98**	**0.94**	**1.00**										
T.D.	**0.98**	**0.98**	**0.93**	**0.99**	**0.96**	**1.00**									
S.T.	**0.97**	**0.99**	**0.97**	**0.96**	**0.99**	**0.97**	**1.00**								
S.G.	**0.85**	**0.88**	**0.95**	**0.82**	**0.93**	**0.86**	**0.92**	**1.00**							
A.U. 1	**0.90**	**0.91**	**0.97**	**0.86**	**0.96**	**0.90**	**0.95**	**0.97**	**1.00**						
A.U. 2	**0.92**	**0.93**	**0.98**	**0.89**	**0.98**	**0.91**	**0.96**	**0.98**	**0.98**	**1.00**					
S.M.	**0.92**	**0.93**	**0.97**	**0.89**	**0.98**	**0.91**	**0.96**	**0.95**	**0.98**	**0.98**	**1.00**				
T.E.	**0.91**	**0.92**	**0.98**	**0.87**	**0.96**	**0.90**	**0.94**	**0.97**	**0.97**	**0.98**	**0.96**	**1.00**			
N.P.	**0.97**	**0.96**	**0.98**	**0.95**	**0.99**	**0.96**	**0.97**	**0.93**	**0.96**	**0.97**	**0.97**	**0.96**	**1.00**		
L.G.	**0.98**	**0.98**	**0.96**	**0.97**	**0.97**	**0.98**	**0.99**	**0.88**	**0.94**	**0.94**	**0.95**	**0.92**	**0.97**	**1.00**	
N.Pa.	**0.97**	**0.98**	**0.97**	**0.96**	**0.97**	**0.97**	**0.98**	**0.91**	**0.95**	**0.95**	**0.96**	**0.94**	**0.97**	**0.99**	**1.00**

Legend: bolded correlations are significant at $p < 0.05$ (N = 52).

Table A5. Correlations of the hip joint angle.

	B.H. 1	**B.H. 2**	**C.B.**	**M.R.**	**V.M.**	**T.D.**	**S.T.**	**S.G.**	**A.U. 1**	**A.U. 2**	**S.M.**	**T.E.**	**N.P.**	**L.G.**	**N.Pa.**
B.H. 1	**1.00**														
B.H. 2	**0.93**	**1.00**													
C.B.	**0.91**	**0.96**	**1.00**												
M.R.	**0.82**	**0.86**	**0.82**	**1.00**											
V.M.	**0.94**	**0.96**	**0.96**	**0.89**	**1.00**										
T.D.	**0.80**	0.73	0.65	**0.85**	0.76	**1.00**									
S.T.	**0.93**	**0.93**	**0.96**	**0.83**	**0.97**	0.71	**1.00**								
S.G.	**0.91**	**0.90**	**0.91**	0.63	**0.89**	0.58	**0.90**	**1.00**							
A.U. 1	**0.86**	**0.81**	**0.81**	0.52	**0.82**	0.59	**0.83**	**0.96**	**1.00**						
A.U. 2	**0.84**	**0.84**	**0.84**	0.54	**0.83**	0.54	**0.82**	**0.97**	**0.97**	**1.00**					
S.M.	**0.90**	**0.81**	**0.88**	0.66	**0.88**	0.55	**0.94**	**0.88**	**0.84**	**0.81**	**1.00**				
T.E.	**0.94**	**0.90**	**0.91**	0.77	**0.95**	0.70	**0.97**	**0.91**	**0.86**	**0.84**	**0.95**	**1.00**			
N.P.	**0.95**	**0.96**	**0.98**	**0.84**	**0.97**	0.69	**0.97**	**0.90**	0.80	**0.82**	**0.92**	**0.95**	**1.00**		
L.G.	**0.89**	**0.87**	**0.95**	0.74	**0.91**	0.63	**0.95**	**0.88**	0.80	**0.81**	**0.92**	**0.93**	**0.95**	**1.00**	
N.Pa.	0.78	**0.88**	**0.90**	0.60	**0.85**	0.44	**0.83**	**0.93**	**0.86**	**0.93**	0.78	**0.81**	**0.86**	**0.85**	**1.00**

Legend: bolded correlations are significant at $p < 0.05$ (N = 52).

Table A6. Correlations of the hip joint angular velocity.

	B.H. 1	**B.H. 2**	**C.B.**	**M.R.**	**V.M.**	**T.D.**	**S.T.**	**S.G.**	**A.U. 1**	**A.U. 2**	**S.M.**	**T.E.**	**N.P.**	**L.G.**	**N.Pa.**
B.H. 1	**1.00**														
B.H. 2	0.79	**1.00**													
C.B.	0.63	0.74	**1.00**												
M.R.	**0.82**	0.76	0.54	**1.00**											
V.M.	0.80	0.79	0.73	0.84	**1.00**										
T.D.	0.54	0.39	0.16	0.60	0.56	**1.00**									
S.T.	0.64	0.71	0.75	0.75	0.77	0.34	**1.00**								
S.G.	0.70	**0.83**	0.80	0.74	0.78	0.31	0.68	**1.00**							
A.U. 1	0.73	0.80	0.71	0.79	**0.87**	0.55	0.68	**0.82**	**1.00**						
A.U. 2	0.59	0.72	0.62	0.66	0.66	0.34	0.60	0.76	**0.84**	**1.00**					
S.M.	0.74	0.57	0.73	0.65	0.77	0.20	0.78	0.58	0.57	0.42	**1.00**				
T.E.	0.69	0.69	0.65	0.70	0.76	0.45	0.73	0.71	0.56	0.55	0.72	**1.00**			
N.P.	0.78	0.76	0.79	0.65	0.80	0.28	0.76	0.73	0.63	0.50	**0.86**	0.75	**1.00**		
L.G.	0.44	0.40	0.75	0.31	0.57	0.11	0.63	0.56	0.47	0.36	0.74	0.65	0.67	**1.00**	
N.Pa.	0.50	0.67	0.75	0.46	0.67	0.10	0.53	0.78	0.72	0.74	0.49	0.50	0.62	0.60	**1.00**

Legend: bolded correlations are significant at $p < 0.05$ (N = 52).

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