ESTIMATING HORIZONTAL DISPLACEMENT DEDUCTION IN TRAMPOLINE GYMNASTICS BY MEANS OF CONSTANT AND VARIABLE ERRORS OF LANDING POSITIONS: A NEW GOLD STANDARD?

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Original article

Abstract

The final result in competitive trampoline gymnastics is composed of different subscores. These contribute differentially to the final score and result in a gymnast's ranking. The present study was designed to investigate the impact that alternative score calculations of the horizontal displacement of the landing positions on the trampoline's cloth would have on the final competition result. Different approaches for determining a precision measure were compared to the current standard of horizontal displacement deduction. These approaches for calculating precision measures were: (a) "total distance," (b) the "convex-hull approach," and (c) the "error approach." Results showed that an alternative approach was more precise and differentiated better between gymnasts. The resulting changed rankings are compared to the official final score of the competition in order to demonstrate the impact of alternative calculations.

Keywords: *trampoline gymnastics, constant error, variable error, performance.*

INTRODUCTION

Trampoline competitions comprise three routines each containing 10 elements. In the qualifying rounds, gymnasts perform a set routine; in the finals, a voluntary routine. The first routine in the preliminary round (set) includes 10 stated skills. In a competition, the judges' task is to evaluate a particular routine and to generate a total score for this routine based on evaluating the overall degree of difficulty (DD), the overall skill execution (E), the measurement of time-of-flight duration (ToF), and the recently added measurement of horizontal displacement (HD; see regulations of the Fédération Internationale de Gymnastique, FIG Executive Committee (2017). According to the FIG regulations, the degree of difficulty, execution, time of flight, and horizontal displacement scores are added to produce a final total value by means of the following equation:

Total Value = DD + E (max. 20 pts) + ToF + HD (max. 10 pts) - penalty deductions

For a long time, the total value in trampoline competitions consisted of two variables: the degree of difficulty and the overall skill execution. To make trampoline gymnastics more attractive and the evaluation of gymnasts more objective, the technical committee of the FIG introduced the time of flight (ToF) as a new performance value in 2010. The intention was to provide an additional, objective criterion for evaluating athletes' performance. At the same time, trampoline device manufacturers improved the technology of top-class trampolines resulting in higher ejection forces of the trampoline bed and, in turn, longer ToF values. However, this also increased the risk as a result of performing more spectacular routines with potential injury-prone outcomes (Grapton, Lion, Gauchard, Barrault, & Perrin, 2013). To control this risk factor, the technical committee together with the device manufacturers defined a maximal extent of ejection force (see FIG Executive Committee, 2017, for more details). This definition should decrease injury risks while maintaining the sport's attractiveness. Unfortunately, however, numerous injuries demonstrated that defining a maximal extent of ejection forces did not suffice to reduce the risk of injuries (Edouard et al., 2018). As a consequence, the number of break-offs increased tremendously in the following years, making trampoline gymnastics rather less attractive than before. In response, the Technical Committee introduced another weighting criterion, the Horizontal Displacement (HD) value, to reward a jumping pattern closer to the center of the cloth. To measure this HD value, a device used for ToF measurement based on ground reaction forces of the trampoline rack (Horizontal Displacement Trampoline System, Lenk, Hackbarth, Mylo, Weigand, & Ferger, 2016) was now also installed to calculate the athletes' landing positions on the trampoline bed.

The idea behind introducing the HD deduction was to reconstitute a higher level of safety that should result in a lower number of break-offs. In addition, the HD value should make results more precise and fairer. However, the current computation of HD is based on deductions in defined rectangular landing zones on the trampoline bed (see Figure 1). This implies that merely a minor displacement in landing positions between two jumps could mean either a major deduction or none at all, thereby not representing a fine-scaled differentiation between athletes' performances. This article aims to suggest a more objective, precise, safe, and feasible way to include HD values from HDTS into the total evaluation of athletes' performance.

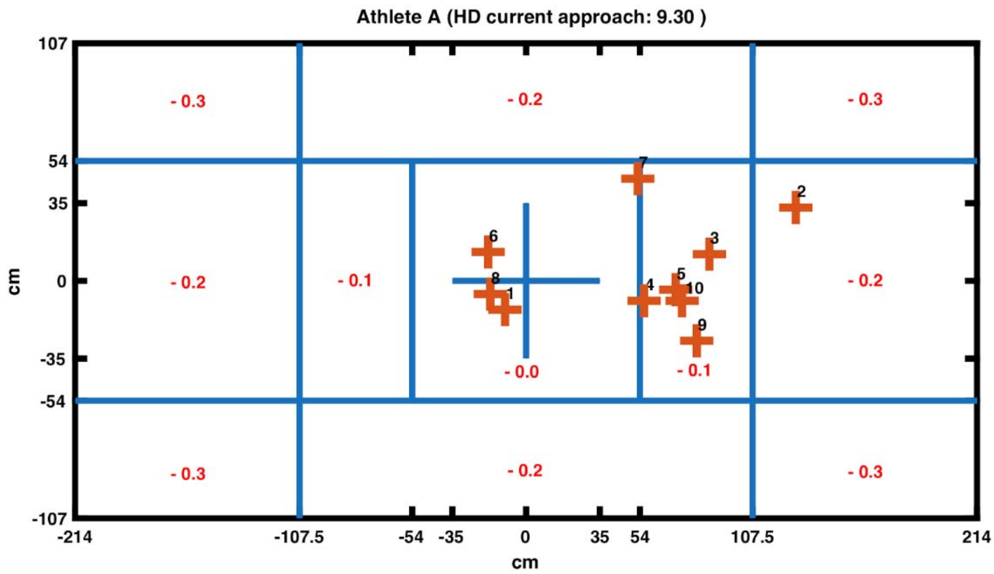

Figure 1. Current HD deduction. Visualization of the different deduction zones and their corresponding deduction value per jump when the landing position is located in the respective zone/rectangle. A representative distribution of jumps of a male athlete during the 2018 German Cup Final is added to the figure to visualize his HD deduction by means of the current "Code of Points" (FIG, 2017).

Two important questions arise when considering the history of implementation of the ToF and HD values in the past years (see Ferger, Zhang, Kölzer, Tiefenbacher, & Müller, 2013; Ferger & Hackbarth, 2017; Lenk et al., 2016): (1) Which role do each of the two variables play in the evaluation of routines in trampoline gymnastics? (2) Which impact does a new HD value have on the final result of a competition when different computations are based on measuring the landing position after each element? The current procedure for addressing Question 1 is as follows: According to the "Code of Points" in the FIG Executive Committee (2017) regulations, the HD value can reach a maximum of 10.0 points. Given the landing position after each element, HD-deduction values are subtracted from this maximum. The current calculation of HD is determined by the deduction of different values (from 0 to 0.3 per jump) derived from partitioning landing positions into different zones (see Figure 1). The landing position is calculated by the HDTS, which measures any force applied to the trampoline bed. The specific relation of ground reaction forces acting on the rack determines the specific landing position on the cloth (see Ferger & Hackbarth, 2017; Lenk et al., 2016, for more details). Using the landing positions of the HDTS, a deduction will apply for each element when any part of the body touches the cloth outside the outer line of the defined zones. Landing in a square zone in the center of the trampoline (108 cm in the longitudinal and 108 cm in the transversal axis; see Figure 1) is the safest landing position after a routine and results in no HD deduction. Landing outside this square zone but in a rectangle of 215 cm longitudinal and 108 cm transversal extent (centered with respect to the midpoint of the trampoline) results in an HD deduction of 0.1 points. Landing outside this rectangle (215 cm x 108 cm) but in a further rectangle of 428 cm longitudinal and 107 cm transversal extent results in an HD deduction of 0.2 points. Landing on the edges outside this rectangle (428 cm x 107 cm) results in an HD deduction of 0.3 points. If all 10 jumps are executed, the maximum possible HD-deduction score can reach 3.0 points, this being the case when all 10 jumps land in the edges outside the rectangle that spans 428 cm longitudinally and 107cm transversally. In comparison, and according to § 21.3 in the "Code of Points" of the FIG Executive Committee (2017), the greatest possible deduction for overall skill execution (E score) can be 5.0 points. Therefore, the current implementation of a precision criterion by means of HD has only a marginal impact on differentiating the final performance, because quite different positions on the bed can lead in sum to the same HD values.

For Question 2, two common measures of error for evaluating outcome in motor skills have been used (Chapanis, 1951, p. 1187). These two measures of error—constant (CE) and variable error (VE)—represent two distinct aspects of performance: bias and variability respectively. CE provides data on how far the outcome has shifted away from the target (i.e., in darts: the distance to bull's eye or the overall accuracy). VE yields information on how variable performance is based on several repetitions—without reference to the target, but with reference to all the other repetitions (i.e., in darts: the inconsistency of 10 throws in a row). In trampoline, both errors are relevant: Due to safety rules, the gymnast should land close to the center of the cloth (CE) as well consistently close to the center (VE, small variability).

Therefore, HD should be counted in terms of the real displacement from the central point. In the error approach proposed here, the displacement (CE) in the longitudinal direction with respect to the center of the trampoline increases from 0.1 to 0.3 points to the outside in all directions and not just in the corners as in the current approach. In addition, depending on the deviation from the midpoint, the displacement in the transverse direction

(VE) increases more rapidly to 0.3 points, because landing in lateral zones is more dangerous. Safety-relevant deviations from the midpoint would then be recorded in a more differentiated manner.

The present study aims to investigate the impact of different HD computations on to the total competition score in trampoline gymnastics. Three different approaches are presented and discussed with respect to the impact they may have on decreasing the risk of major injuries due to unsafe landing patterns by having a differentiating impact (with respect to safe and unsafe jumping patterns) on the total value of the routine performance. Hence, our aim is to determine a reliable, precise, objective, and differentiating HD value that also rewards gymnasts for safe landing patterns.

METHODS

In order to analyze the individual contribution of HD to the total value of a trampoline routine, we used the rankings of the 2017 World Cup Final (Men and Women) in Valladolid, Spain as well as the 2018 Germany Cup Final (Men and Women) in Hamburg. We then compared these rankings and HD values when applying different alternative approaches to compute a HD deduction. For all our computations, we used the HDTS data that reliably measure the horizontal landing position on the trampoline bed (Ferger, Hackbarth, Mylo, Müller, & Zentgraf, 2019). Based on the abscissa and ordinate of the landing positions, we applied three different measures to numerically evaluate the jumping pattern of a 10-jump trampoline routine. For all three measures, the total possible HD deduction amounts to 3.0 and the deduction from 0 points increases stepwise by 0.05 points. To transform the numeric measures of all three approaches into HD values, we used exemplary jumping patterns (see Figure 2) for a just near-to-optimal jumping distribution (see Figure 2A) and a maximally poor jumping distribution (see Figure 2B). We assumed that a just near-to-optimal jumping distribution would be distributed across the inner square around the center of the trampoline (108 cm in the longitudinal and 108 cm in the transversal axis), whereas a maximally poor jumping pattern would be distributed around the edges of the outer rectangle (428 cm x 214 cm).

1. Total Distance Approach

This approach calculates the sum of the distances of each individual landing position from the center of the trampoline resulting in a total distance value. Using our exemplary jumping patterns, we transformed the total distance of the near-to-optimal jumping pattern (d_{min}= 338.0 cm) into a HD deduction of 0.0 points, whereas the total distance of the maximally poor jumping pattern (d_{max}= 1991.7 cm) was transformed into a HD deduction of 3.0 points. Deduction increased stepwise from 0 points by 0.05 points. Distances between d_{min} and d_{max} were transformed linearly into HD deduction values between 0 and 3.0 points. Figure 3A shows a jumping pattern performed during the 2018 German Cup Final applying the total distance approach for HD deduction.

2. The Convex Hull Approach

This method uses the surface area of the convex hull (Hemmer & Schmidt, 2008) to calculate the size of the area used by the athletes. In this case, we defined the convex hull as the smallest area on the trampoline bed including all 10 landing positions. After defining the landing positions that form the convex hull, we calculated the size of the surface area of this hull. Using our exemplary jumping patterns, we transformed the size of the surface area of the just near-to-optimal jumping pattern (A_{min} = 4900 qcm) into an HD deduction of 0 points, whereas we transformed the total distance of the maximally poor jumping pattern (A_{max} = 91592 qcm) into an HD deduction of 3.0 points. We increased deduction stepwise by 0.05 points, and transformed area sizes between A_{min} and

A_{max} linearly into HD deduction values between 0 and 3.0 points. Figure 3B shows a jumping pattern performed during the 2018 German Cup Final applying the convex hull approach for HD deduction.

3. The Error Approach

This approach is based on two common accuracy measures evaluating performance results in motor skill execution (Chapanis, 1951, p. 1187). The first measure to be considered is the constant error (CE) of the landing position in relation to the center of the trampoline bed. We defined CE as the sum of all distances from the target (center of the trampoline bed) divided by the total number of jumps performed: the higher the CE, the poorer the jumping performance with respect to the precision of the jumping pattern. The second measure is the variable error (VE) of the landing position. We defined VE as the square root of the sum of squares of the mean landing position subtracted from the landing position of each jump divided by the total number of jumps performed: the higher the VE, the poorer the jumping performance with respect to the stability of the jumping pattern.

In our approach, we combined both accuracy values to compute an accuracy score that integrates the precision and stability of performance regarding the HD on the trampoline bed. We double-weighted the ordinate of each landing position to control the differences of the bed length in the abscissa (428 cm) versus the ordinate (214 cm) axes. This adjustment in weighting was necessary in order to guarantee that the extent of deviation would be of equal value in both directions. We also double-weighted landing positions that were 107.5 cm off-center in the abscissa and/or 54 cm off-center in the ordinate axes in order to penalize certain unsafe landing areas in a stronger way.

To determine the calculation of the error approach precisely, we carried out the following steps: (a) Prior to all CE or VE measures, we controlled differences in bed length by multiplying the landing position in the ordinate by 2. (b) Using these adjusted landing coordinates, we calculated the distance D of each landing position with regard to the coordinate center (D = sqrt[xi^2 + 2 * yi^2]). We gave double weight to the y-axis in order to penalize certain unsafe landing areas in this direction in a stronger way (safety adjustment). (c) Using the distance measures for each individual jump, we calculated CE and VE with the following equations: CE = sum(Di)/N, VE = sqrt(sum((Di-Mi)^2/N)). Using CE and VE, we calculated an error value E = CE + VE.

Taking all these requirements into account, we calculated an accuracy value and transformed it into an HD deduction between 0 and 0.3 points after each individual jump. We increased deduction stepwise by 0.05 points. We used the exemplary jumping patterns shown in Figure 2 as references for no HD deduction (see Figure 2A) and maximum HD deduction (see Figure 2B). Figure 3C shows a jumping pattern performed during the 2018 German Cup Final applying the accuracy (precision and stability) approach for HD deduction.

At last, we used the data of the preliminary contest of both competitions to review the different approaches. We hypothized to find differences in the approaches based on stable and variable conditions. The first routine in the Qualifying Round are often the basic exercises, characterized by more stable jumping patterns and less degree of difficulty. The second routine in the Qualifying Round are voluntary routines with a higher degree of difficulty and variable jumping pattern. Therefore, individual trampoline results were collected for men and women from different age groups (N=172 routines). The individual results for the two requirements (stable und variable pattern) were gathered from the HD measurement device. Overall, four different HD scores for each participant of qualification were noted for later data analysis.

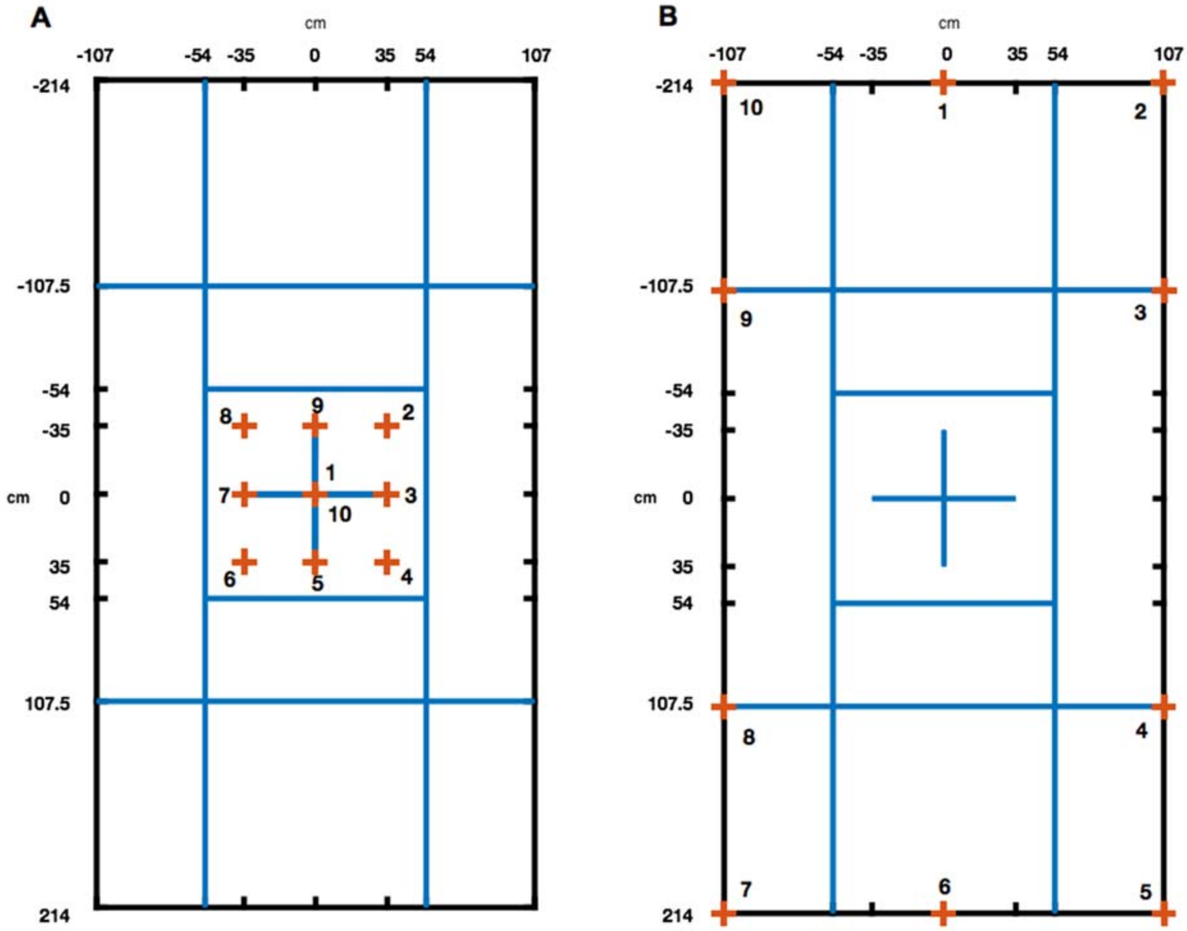

Figure 2. Exemplary jumping patterns. The pattern in Figure 2A represents a just near-to-optimal jumping pattern that does not result in any HD deduction. We suggest using this pattern as the no-deduction reference to scale the metrics computed in Approaches 1 to 3. The pattern in Figure 2B represents a maximally poor jumping pattern that results in maximum HD deduction. We suggest using this pattern as the maximum deduction reference to scale the metrics computed in Approaches 1 to 3.

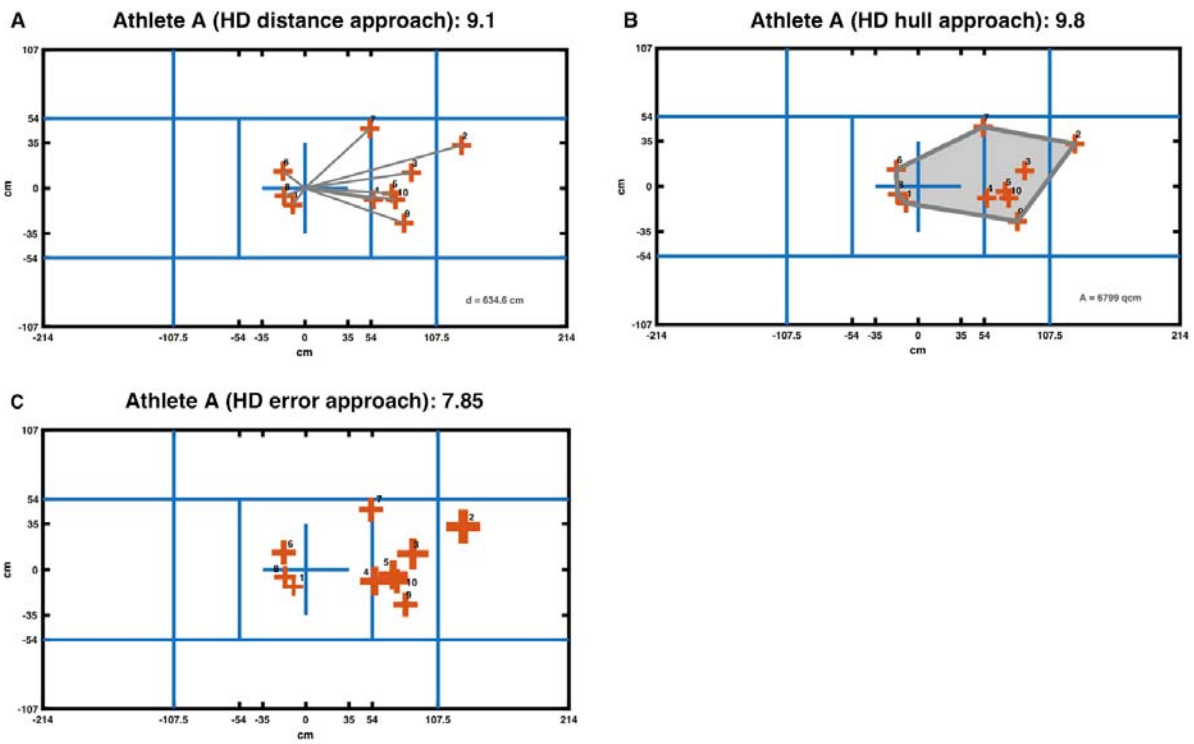

Figure 3. Alternative HD calculation approaches.

Figure 3A. Total distance approach. Visualization of a male athlete's jumping distribution during the 2017 German Cup Final illustrating the total distance measurement approach. According to the transformation of the numerical distance value (d = 634.6 cm), this jumping distribution would result in an HD value of 9.1.

Figure 3B. Convex hull approach. Visualization of a male athlete's jumping distribution during the 2017 German Cup Final illustrating the convex hull approach. The grey area illustrates the trampoline bed area used by the athlete. According to the transformation of the numerical size of the surface area of the convex hull (6799 qcm) including all 10 jumps, this distribution of landing positions would result in an HD value of 9.8.

Figure 3C. Error approach. Visualization of a male athlete's jumping distribution during the 2017 German Cup Final illustrating the precision and stability measurement approach based on common accuracy measures used in motor skill learning. Size and thickness of the red crosses indicate the amount of deduction for the corresponding jump. Bigger and thicker crosses indicate a higher deduction. According to the transformation of the numerical accuracy value after all 10 jumps, this distribution of landing positions would result in a HD value of 7.85.

RESULTS

Looking at the distributions of HD values for the calculations using Approaches 1 to 3 for both competitions, it became obvious that the different approaches demonstrated significant differences in the distributions of HD values across all athletes taking part in the finals (see Tables 1–2 and Figures 4–5).

During the 2017 World Cup finals in Valladolid, two judges who were responsible for evaluating the horizontal displacement determined the HD value. Their marks were averaged and used as a score for the horizontal displacement as provided in §18.2.6.3 Code of Points. The electronic measurement device HDTS was in use at the same time, but these values were not included in the final evaluation. Furthermore, the table indicates differences between the judges' scores and the measurement device. These differences will be taken into account and explained in the discussion.

Table 1
Athlete's Results in the 2017 World Cup Final Competition in Valladolid, Spain.

Rank	Female athletes	E	DD	ToF	HD	HDTS	P	Total	HDTS cur	HD dist.	HD hull	HD error
1	ZHU X.	17.60	14.4	16.305	9.45	9.5		57.755	9.5	9.55	9.95	9.40
2	PAVLOVA Y.	16.20	15.0	16.495	9.10	9.3		56.795	9.3	8.70	9.90	9.15
3	PIATRENIA T.	16.10	15.0	16.265	9.05	9.3		56.415	9.3	8.95	9.85	9.00
4	GALLAGHER L.	16.70	14.2	16.190	9.20	9.4		56.290	9.4	9.00	9.90	9.15
5	MORI H.	17.40	12.0	16.685	8.95	9.5		55.035	9.5	9.25	9.75	9.10
6	KOCHESOK S.	15.50	14.4	15.970	9.20	9.2	0.2	54.870	9.2	8.80	9.80	9.25
7	GOLOVINA L.	15.10	11.5	15.145	7.75	9.1		49.495	9.1	8.65	9.30	8.80
8	ZHONG X.	4.80	4.9	5.025	2.50	3.3		17.225	3.3	3.30	3.80	3.25
Rank	Male athletes											
1	DONG D.	16.90	17.8	17.760	8.80	9.5		61.260	9.5	9.45	9.75	9.35
2	SCHMIDT D.	17.00	17.8	17.965	8.50	9.3	0.4	60.865	9.3	8.95	9.70	8.90
3	USHAKOV D.	17.00	17.3	17.765	8.60	9.4		60.665	9.4	9.20	9.80	9.30
4	KISHI D.	16.60	17.1	17.485	8.65	7.9		59.835	7.9	8.00	8.55	7.90
5	TU X.	15.60	17.8	16.945	8.65	9.0	0.4	58.395	9.0	9.00	9.90	9.15
6	HERNANDEZ A.	14.00	17.6	16.775	8.95	9.1		57.325	9.1	9.00	9.65	8.95
7	MARTIN J.	14.60	16.1	17.520	8.80	8.7		57.020	8.7			
8	HANCHAROU U.	10.00	11.4	10.875	5.35	5.3		37.625	5.3	5.35	5.80	5.25
9	AZARIAN S.	9.90	10.7	11.130	5.30	6.0		37.030	6.0	6.05	6.65	5.95

Note: HD was determined by judges as well as by the HDTS during this competition. In the calculation of the result, however, only the values of the judges were included.

Table 2
Athlete's results in the 2018 Germany Cup Final Competition in Hamburg, Germany.

Rank	Female 11/12	E	DD	ToF	HD	HDTS	P	Total	HDTS cur	HD dist.	HD hull	HD error
1	MÖLLER M.	16.5	8.9	14.180	9.5	9.5		49.080	9.5	9.15	9.95	9.50
2	RONSIEK H.	16.1	6.5	14.725	9.3	9.3		46.625	9.3	8.90	9.60	8.95
3	EISLÖFFEL A.	15.3	7.8	13.135	9.5	9.5		45.735	9.5	8.95	9.70	9.35
4	KELM J.	13.8	6.7	14.095	9.5	9.5		44.095	9.5	9.25	9.80	9.45
5	VOLIKOVA E.	15.3	5.8	13.190	9.0	9.0		43.290	9.0	9.10	9.90	8.85
6	TUTTAS S.	13.2	7.2	12.780	9.1	9.1		42.280	9.1	9.30	9.80	8.90

7	SAPRAUTZKI I.	5.8	4	5.360	3.7	3.7	18.860	3.7	3.60	3.85	3.70
Rank	Female 13/14										
1	IMLE V.	17.3	8.6	14.820	9.2	9.2	49.920	9.2	9.15	9.85	9.25
2	BRAAF L.	17.4	8.7	13.825	9.6	9.6	49.525	9.6	9.10	9.85	9.20
3	FREY L.	16.8	8.4	14.550	9.5	9.5	49.250	9.5	9.25	9.85	9.30
4	DONECHEVA P.	15.6	8.8	14.510	9.8	9.8	48.710	9.8	9.35	9.95	9.50
5	LANGNER S.	16.3	8.2	14.220	9.5	9.5	48.220	9.5	9.20	9.70	9.25
6	RADFELDER M.	16.4	7.2	13.420	9.4	9.4	46.420	9.4	9.10	9.65	9.20
7	KOLA S.	15.8	7.6	13.840	9.1	9.1	46.340	9.1	8.90	9.60	8.75
8	SCHNEIDER F.	15.0	8.0	13.635	9.1	9.1	45.735	9.1	8.60	9.75	8.50
Rank	Female 15/16										
1	ZIMMERHA J.	16.7	8.6	14.350	9.7	9.7	49.350	9.7	9.50	9.90	9.50
2	SCHULDT C.	16.9	8.1	14.905	9.4	9.4	49.305	9.4	9.50	9.95	9.50
3	PAPE N.	16.5	8.4	14.410	9.4	9.4	48.710	9.4	9.30	9.90	9.20
4	LUEG F.	16.3	8.2	13.705	9.5	9.5	47.705	9.5	9.20	9.80	9.30
5	LAUHÖFER S.	14.8	8.9	14.270	9.6	9.6	47.570	9.6	9.15	9.75	9.15
6	SEIDEL L.	17.1	6.1	14.435	9.4	9.4	47.035	9.4	9.10	9.60	9.20
7	SCHWARTZ N.	14.9	8.6	13.075	9.3	9.1	46.760	9.1	8.95	9.80	9.05
7	HENSELEIT N.	15.2	8.4	13.860	9.3	9.3	46.760	9.3	9.00	9.80	9.10
Rank	Female 17+										
1	BAUMANN I.	17.9	8.1	15.335	9.5	9.5	50.835	9.5	9.50	9.70	9.50
2	BUCHHOLZ C.	16.4	10	14.680	9.5	9.5	50.580	9.5	8.80	9.70	8.85
3	MÜLLER S.	17.1	8.6	15.675	9.1	9.1	50.475	9.1	9.30	9.85	9.45
4	SCHÜLLER F.	16.8	9	13.990	9.5	9.5	49.290	9.5	9.05	9.90	8.85
5	STAIBER S.	17.1	8.2	14.515	9.0	9.0	48.815	9.0	8.85	9.70	8.85
6	MAYER M.	18.2	5.8	14.785	9.6	9.6	48.385	9.6	9.50	10.00	9.55
7	SÜß A.	14.7	7.6	14.020	9.1	9.1	45.420	9.1	8.95	9.90	9.00
8	ADAM L.	8.5	6.9	7.965	4.7	5.5	28.065	5.5	5.65	5.95	5.55
9	SCHOLZ A.	3.0	2.5	2.955	1.8	3.4	10.255	3.4	3.30	3.90	3.40
Rank	Male 11/12										
1	ESCHKE R.	15.8	8.0	13.620	9.3	9.3	46.720	9.3	9.20	9.80	9.10
2	BAUSCHKE J.	13.6	8.1	13.510	9.4	9.4	44.610	9.4	9.25	9.80	9.30

3	THOMSON A.	15.6	8.2	13.705	9.11	9.1		46.605	9.1	9.00	9.90	8.80
4	STRIESE H.	14.8	7.2	11.920	7.2	9.6		43.520	9.6	9.25	9.90	9.50
5	DROBINOHA D.	14.80	6.6	12.405	9.5	9.5		43.305	9.5	9.00	9.85	9.50
Rank	Male 13/14											
1	HAGEN L.	15.7	9.5	15.320	9.4	9.4		49.920	9.4	8.80	9.85	8.90
2	GARMAN L.	16.5	8.5	14.705	9.6	9.6		49.305	9.6	9.45	9.85	9.50
3	RISCH V.	16.4	8.2	14.850	9.4	9.4		48.850	9.4	9.30	9.85	9.25
4	GLADJUK M.	14.8	6.9	13.265	9.3	9.3		44.265	9.3	9.05	9.90	9.50
5	LITTERS L.	13.7	7.8	13.050	9.3	9.3		43.850	9.3	9.10	9.90	8.95
6	BRAMMANN L.	12.4	8.0	14.000	9.3	9.3		43.400	9.3	9.00	9.75	9.45
7	FAHRON .	13.3	8.1	12.715	9.0	9.0		43.115	9.0	8.95	9.65	9.05
8	DANNENBER J.	13	7.1	11.350	8.7	9.6		40.150	9.6	9.50	9.95	9.60
Rank	Male 15/16											
1	RÖSLER M.	15.7	13.3	15.440	9.6	9.6		54.040	9.6	9.40	9.85	9.50
2	LAUXTERM C.	15.8	13.4	15.800	9	9.0	0.3	53.700	9.0	8.95	9.55	8.95
3	BUDDE Max	15.9	10.8	15.335	9.3	9.3		51.335	9.3	8.95	9.85	8.85
4	GASCHE J.	15.2	9.7	15.355	8.9	8.9		49.155	8.9	9.10	9.55	8.95
5	HOFMANN S.	15.3	10.4	14.945	8.8	8.8	0.3	49.145	8.8	8.95	9.60	8.70
6	MELNICHUK E.	14.5	10.3	14.810	9.2	9.2		48.810	9.2	9.15	9.65	9.00
7	EHLERT P.	9.5	11.1	14.385	9.1	9.1		44.085	9.1	9.05	9.80	8.80
8	FRAHM J.	4.1	3.8	4.765	2.8	3.6		15.465	3.6	3.35	3.70	3.35
Rank	Male 17+											
1	PFLEIDERER M	15.2	16.2	16.770	9.8	9.8		57.970	9.8	9.55	9.90	9.60
2	SONN K.	16.2	15.8	16.570	9.3	9.3	0.3	57.570	9.3	9.00	9.70	9.00
3	VOGEL F.	15.7	15.6	16.750	9.6	9.6		57.650	9.6	9.45	9.90	9.50
4	SCHMIDT D.	15.9	15.4	16.290	9.6	9.6		57.190	9.6	9.45	9.75	9.50
5	HARTMANN F.	14.9	14.6	15.755	9.2	9.2		54.455	9.2	8.75	9.60	8.95
6	KUHNERT C.	14.9	14.2	15.970	9.3	9.3		54.370	9.3	9.00	9.85	8.95
7	SCHULDT M.	14.7	14.0	16.300	9.3	9.3		54.300	9.3	8.75	9.65	8.60
8	BRANDT D.	11.9	11.8	15.550	8.8	8.8		48.050	8.8	8.90	9.45	9.00
9	WREN D.	12.4	10.5	13.260	7.1	7.9		43.260	7.9	8.20	8.60	7.85
10	BEST M.	11.1	10.1	10.025	5.7	6.5		36.925	6.5	6.35	6.80	6.30

11	NOWAK T.	3.2	3	3.490	1.8	2.6	11.490	2.6	2.60	2.95	2.55
12	EMIR C.	1.6	1.8	1.750	0.8	2.2	05.950	2.2	2.50	3.00	2.85

Relating the jumping patterns of all athletes (see appendix) to the HD values based on the *current* and *Convex Hull* approaches, Figure 4 and Figure 5 clearly demonstrated that these approaches did not really differentiate between the jumping performances (regarding the horizontal displacement) of the athletes.

In contrast, the *Total Distance* and *Error* approaches produced a stronger differentiation between athletes as shown in Figure 6. They also addressed the issue that only jumping patterns that were distributed precisely around the center of the trampoline bed (108 cm in the longitudinal and 108 cm in the transversal axis) would be rewarded by a high HD value. When comparing the *Total Distance* with the *Error* approach, we saw that the *Error* approach displayed a higher degree of differentiation that might due to implementing a stability measure for the jumping patterns in this approach.

Figure 6 shows the impact of the *Error* approach based on nearly identical results in the part scores (execution, difficulty, and ToF). The *current* approach clearly differentiated between the jumping patterns, whereas the *Error* approach differentiated better by rewarding jumping in the middle of the device. In addition, this better differentiation led to a changed ranking order despite identical results in the part scores.

The MANOVA showed significant main effects of the requirement jumping pattern F (1, 680) =107.140, $p < .01$ and the different approaches, F (3, 680) = 231.474, $p < .01$. There was an additonal significant interaction effect of jumping pattern x approach F (3, 680) = 5.279, $p < .01$. All four approaches varied as a function of the jumping pattern. In particular, error approach exhibited in average lower scores for stable and variable patterns.

As a consequence of this, the total score varied as a function of the error approach. In particular, there is a shift in the podium of the world cup in Spain (see Table 3 and figure 6).

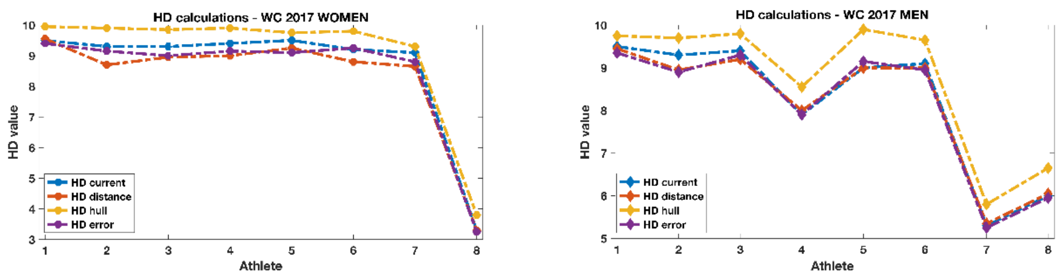

Figure 4. Distribution of HD values for WM 2017. The HD values of all athletes at the World Cup Final 2017 are plotted separately for the different calculation approaches including the currently valid HD calculation. Subfigure 4A shows the distribution of HD values for the women’s final; Subfigure 4B, for the men’s final.

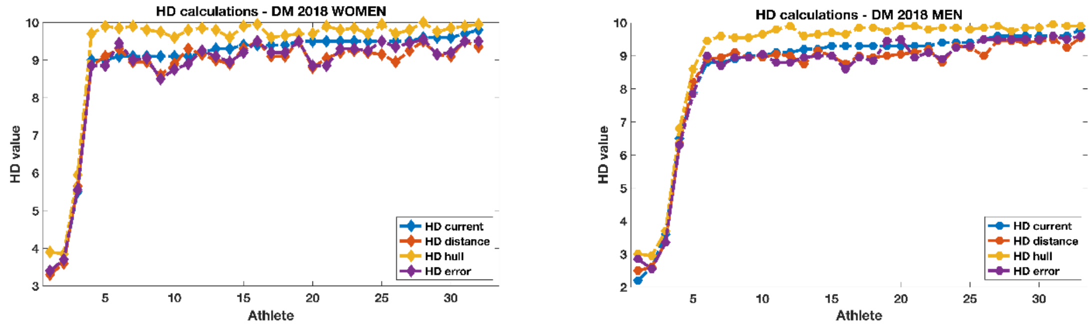

Figure 5. Distribution of HD values for DM 2018. The HD values of all athletes of the German Cup Final 2018 are plotted separately for the different calculation approaches including the currently valid HD calculation. Subfigure 5A shows the distribution of HD values for the women's final; Subfigure 5B, for the men's final. The HD values of the athletes (x-scale) ordered on decreasing HD current deductions.

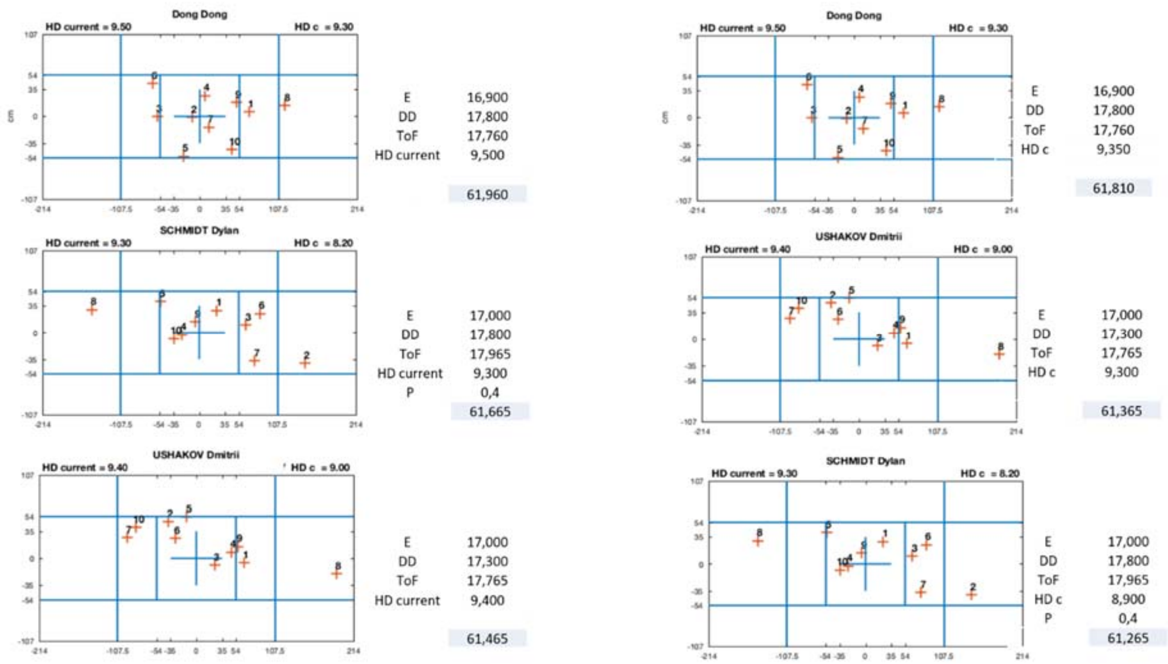

Figure 6. Impact of the error approach on the result in the World Cup 2017 in Spain. Using the Error approach changes the order on the podium.

Table 3
Shifted ranking in the 2017 World Cup Final Competition Men in Valladolid, Spain.

Rank	Male athletes	curr	distance	hull	error
1	DONG D.	61.960	61.910	62.210	61.305
2	SCHMIDT D.	61.665	61.315	62.065	60.780
3	USHAKOV D.	61.465	61.265	61.865	60.850

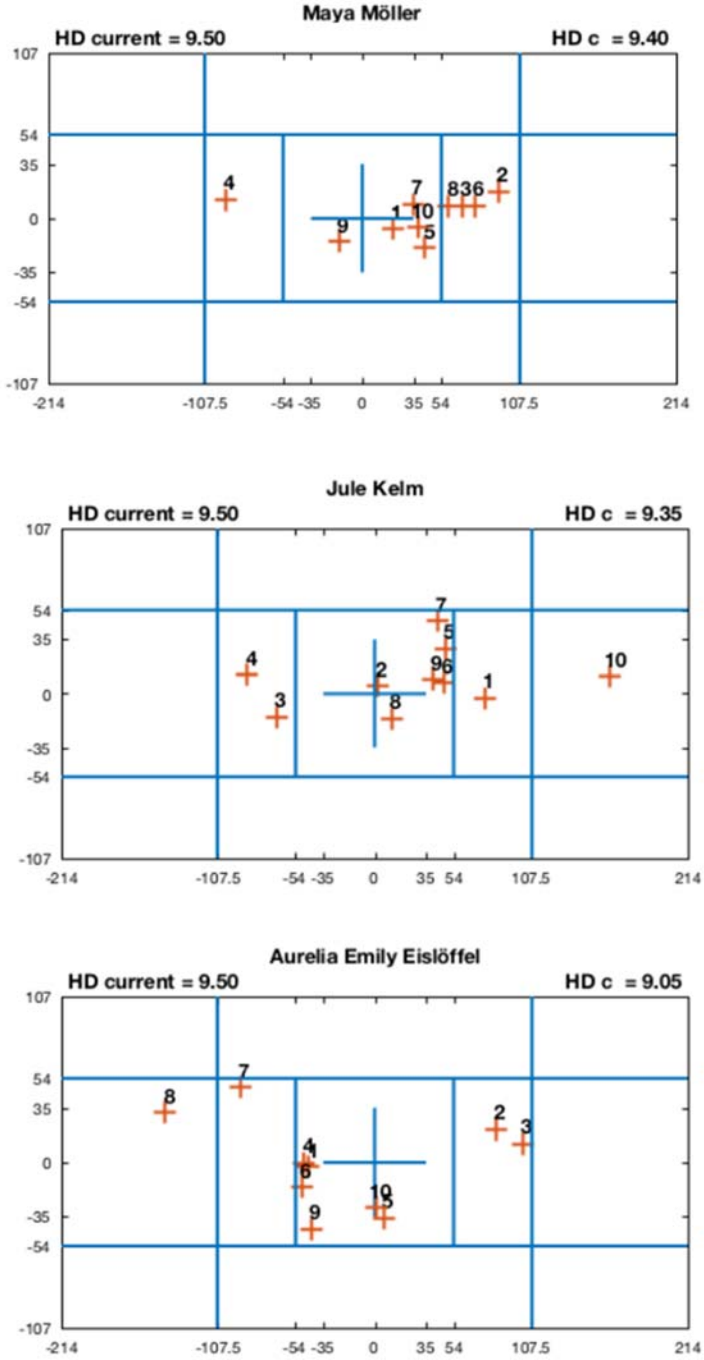

Figure 7. Changing the HD value using the Error approach.

DISCUSSION

This article introduced different approaches to scoring overall performance of trampoline routines based on different bases of calculation. The motivation for using different bases of calculation was to differentiate better between overall performances.

During competitions, athletes have to perform so-called routines that are made up of sequences of jumps. A routine starts with a number of straight jumps to gain momentum. After this preparation, the athlete has to perform a sequence of 10 jumps from a set of predefined jump classes. Then, the judges' task is to assess the routine with respect to its execution and its degree of difficulty. Time of flight and horizontal displacement are measured by the HDTS device. The initial point is the different weighting of the partial values in the overall performance. We evaluated the overall performance depending on HD in a realistic trampolining scenario. Furthermore, we discussed how the use of alternative HD measures affects the overall results. As our main contribution, we discussed suitable calculations of HD. Based on real data from several competitions, we introduced real-valued calculations. Furthermore, we presented a strategy to enhance the influence of certain parameters. In this evaluation, we considered three different bases of calculation:

1. The Total Distance approach
2. The Convex Hull approach
3. The Error approach

As Tables 1 and 2 show, the impact of calculation methods varies. This shows that the proposed Approach 3 is capable of capturing overall performance in a more differentiated manner. When using Approach 3, results are generally more distinguishable than when using the other approaches. Hence, athletes benefit from the use of Approach 3. A good example of how Approach 3 generally improves the overall results is shown in Figure 7. Here, the variances within the routine are similar among athletes (1/2) and result in similar HD values, even though the jump pattern is different with respect to accuracy and stability.

If jumping patterns lead to identical results in the HD value using the current approach, the Error approach then produces a better differentiation between the patterns, determines the precise information on overall performance, and provides a fairer assessment of the performance of gymnasts (see Figure 7). Ultimately, the *Error approach* will reward stable jump patterns in the middle of the device and thus support safe jumping.

Furthermore, the table indicates differences between the judges' scores and the measurement device. When no measurement system is available in FIG competitions, judges need to determine the HD score visually (FIG Executive Committee, 2017). The observed disagreement between judge and system in a few cases (Golovina and Mori see Table 1) is neither an error of technology nor an error of judges. It is rather a problem arising from the different translation of the Code of Points. The judges are instructed to look for the athletes' feet during bed contact. The judge indicates a deduction when one foot is out of the neutral zone. In the same case, the system detects the center of mass inside the neutral zone and makes no deduction (see Ferger & Hackbarth, 2017, for more details). These are the cases in which different deductions can occur.

CONCLUSION

We conclude that adjusting the amount of HD score up to 5.0 pts (similar to the E score), the error approach should be preferred and implemented in the Code of Points. The advantage would be that gymnasts would then jump in a more controlled fashion in the middle of the device and show consistent and stable patterns. This would be a further step toward being able to show a greater differentiation in final performance. All other approaches provoke a higher risk of injury through trying to maximize time of flight (ToF) and E score. The aim of the suggested scoring is to evoke consistent patterns of low variability and high accuracy while simultaneously implementing passive injury prevention measures.

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