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Kinematic influences on ball deviation in men's off-spin bowling in cricket

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Abstract
The purpose of this study was to analyse the kinematics influences on ball deviation of men's in off-spin bowling, and then investigate whether any of the kinematics variables were associated with lateral deviation of ball. Five off-spin bowlers (mean ± s: age = 21.0 ± 0.9 years) were recruited from the Lakshmibai National Institute of Physical Education, India, and their bowling actions were captured by three video cameras (Nikon D-3100, Sony HDR-C-CX200 and Panasonic SDR-H101; 50 frames/second), in a field setting. Six legitimate (excluding ''no balls'') and accurate deliveries were recorded for each participant. The recorded videotapes were digitized and analyzed on motion analysis software (Kinovea Software; 0.8.15). Pearson's Product Moment Correlation was used for evaluating the various relationships of the selected variables towards the performance of spin bowling. Multiple Linear Regression was used for evaluating the contribution of identified biomechanical variables and construction of predictive model. A value of $\alpha = 0.05$ was used for all tests as the criterion to determine the presence or absence of significance. The raw data were calculated in SPSS (Version 20.0). A number of kinematic variables the Angle of Release (r= 0.939), Average Velocity (r= 0.955), Ankle Joint Left(r=0.661), Knee Joint left (r= 0.446) and Elbow Joint left (r= -0.639) were significantly correlated with Lateral Deviation of Ball. The regression equation was reliable as the value of R^2 was 0.974. The four variables selected in that regression equation explain 97.4% of the total variability in lateral deviation of ball was good. Since F-value for that regression model was also highly significant, the model was reliable. At the same time all the regression coefficient in that model were highly significant and therefore all the four variables selected in the model viz. Average Velocity, Elbow joint Right, Angle of release and Ankle joint left were valid in estimating the lateral deviation of ball of a off-spin bowling.

Keywords: Biomechanics, Cricket, Spin bowling, Kinematics.

1. Introduction

In cricket, where fast bowling is often perceived to dominate the game, it is perhaps amazing that the world's three highest "wicket takers" are spin bowlers. The spin bowler achieves rapid flexion of the fingers around one side of the ball, called "finger spin". Finger spin bowling within cricket is created by the movement of the index finger pulling down on the seam of the ball at the point of release.

Previous biomechanical literature regarding cricket bowling has focused on fast bowling kinematics and the contributions to an important factor of fast bowling success, ball velocity. These studies have associated faster run-up velocities with increases in ball velocity (Elliott and Foster, 1984; Elliott *et al*., 1986; Bartlett *et al*., 1996) [5, 13]. Glazier *et al*. (2000) [20] attributed the greater bowling speeds of elite performers not only to run-up speed, but also to increased velocities of each joint. A more recent study has established a link between increased elbow flexion and ball release velocity in fast bowling (Roca *et al*., 2006) [30].

Despite high interest in fast bowling kinematics, little research has been performed on spin bowling, with Ferdinands *et al*. (2001)[17] who performed a rigid body model analysis on one spin bowler and Lloyd *et al*. (2000)[24] who published a case study on the bowling action of Muttiah Muralitharan, providing some quantification to this bowling form. With limited qualitatively based books by Philpott (1973, 1978) [27, 28] and Brayshaw (1978) [7], the legality of bowling actions with research focusing on the bowlers technique (Aginsky & Noakes, 2010;Lloyd, Alderson, & Elliott, 2000; Portus, Rosemond, &Rath, 2006)[2, 24, 29], improving kinematic modelling techniques (Chin, Lloyd, Alderson, Elliott, & Mills, 2010; Elliott & Alderson, 2007)[11, 15], quantifying the measurement differences between video and motion analysis techniques (Elliott, Alderson, & Denver, 2007)[16], the effect of altering elbow kinematics on ball speeds (Marshall & Ferdinands, 2003)[26] and the investigation of elbow extension angular velocity as a criterion measure for illegal actions (Ferdinands & Kersting, 2007) [18], the only exception is Chin *et al*. (2009) [10], who tested multiple kinematic variables, although they limited the sample to off-spin bowlers.

To date, there is lack of scientific data that provides a biomechanical model to examining how off-spin bowlers achieve their various ball deviations in an attempt to deceive the batsman. However, the success of off-spin bowlers is not reflected in the scientific literature, the limited research into the basic mechanisms underlying specifically off-spin bowling in cricket highlights the need for more information directly applicable to the cricketer. While there are many facets that contribute to a successful off-spin bowler, no study has well thought-out all aspects of the spinning cricket ball with off-spin bowlers, suggesting a need for a more clear and accurate model of off-spin bowling; therefore to identify key mechanical features of off-spin bowling of high-performance cricket players from university levels. The purpose of this paper was to investigate the relationship of identified biomechanical variables with lateral deviation of ball in off-spin bowling and to identify the biomechanical variables which contribute significantly towards lateral deviation of ball in off-spin bowling. And develop a regression model for prediction of lateral deviation of ball in off-spin.

2. Methods

2.1 Participants

Five off-spin bowlers were recruited from Lakshmibai National Institute of Physical Education by using consecutive sampling. These bowlers were interuniversity level players at this age bracket (mean age, 21.0 ± 0.9 years; height, 178.7 ± 6.2 cm; weight, 73.9 ± 11.2 kg). To aid logistics, all bowlers were right-handed. They had represented their top team in the university cricket tournament. The participants were provided with an information sheet clearly establishing the benefits from the bowling analysis and their rights as a participant. All subjects underwent the same testing protocol and were injury free at the time of testing. Before the experiment, consent forms were collected.

2.2 Experimental Protocol

The participants were instructed to undertake a cricket related warm-up activity of their choice. Each bowler was allowed an over (six deliveries) of practice deliveries to aid familiarization with the test environment. An over at maximum effort was then bowled. Each bowler bowled six deliveries and six legitimate (excluding ‘‘no balls’’) and accurate deliveries were recorded for each participant and selected for biomechanical analysis of off-spin bowling. All deliveries were bowled with a standard match Kookaburra ball (mass of 0.156± 0.163 kg and circumference of 0.224± 0.229 m) at marked target areas on the pitch, at a ‘‘good length’’ (11.5 – 14.5 m from the bowling crease). A successful trial required the ball to land within the marked areas were selected for biomechanical analysis. White stickers (25 mm in diameter) were placed on the subjects bodies at sixteen anatomical joint centres (right and left: toe of boot, ankle, knee, hip, shoulder, elbow, wrist, and index finger knuckle) to facilitate the automatic video image digitization. For the purpose of the present study, ten independent variables (such as right and left: Ankle Joints, Knee Joints, Hip Joints, Shoulder Joints, Elbow Joints & Wrist Joints, Height of Centre of Gravity at Release, Height of Release, Angle of Release, Average Velocity) were selected to analysis the performance of the bowlers. The performance was recorded on the basis of the lateral deviation of the ball (dependent variable); i.e. the lateral displacement of the ball between the point of landing to the imaginary point of intersection between stump line (bowling crease) and path of ball.

2.3 Filming Protocol & Analysis of film

Analysis of off-spin bowling was conducted by capturing the outdoor bowling action trials of each participant on video. Three video cameras (Nikon D-3100, Sony HDR-C-CX200 and Panasonic SDR-H101; 50 frames/second), in a field setting was employed in this study. The camera was set-up on a rigid tripod.

2.4 Camera set-up

First camera (Nikon D-3100) was positioned perpendicular to the sagittal plane and so as that the bowler’s arm gives approximately a 90^{o} between their respective optical axes. The distance of the camera from the subject was 5.03 meters away and the height of the lens was 1.00 meters from the ground, so that the motion of subjects on the sagittal plane could be recorded and the purpose of measuring the different joint angles and angle of release of the ball. The second camera (Sony HDR-C-CX200) was positioned on the frontal plane, behind the stumps for measured deviation of ball. The distance of the camera from the stumps was 2.75 meters away and the height of the lens was 0.95 meters from the ground. For the purpose of measuring the velocity of the ball, and the third camera (Panasonic SDR-H101) was placed on the sagittal plane, perpendicular to the center of the pitch. The distance of the camera from the center of the pitch was 22.50 meters away and the height of the lens was 1.00 meters from the ground. A hurdle was filmed prior to filming of subjects for reference of height and distance. The recorded videotapes were digitized and analyzed on a motion analysis system (Kinovea Software; 0.8.15).

Kinovea software was used to measure the angles at different joints. Segmentation method was used to measure the Center of gravity at release movement (suggested by James G. Hay, 1978). Ball release height was the vertical distance from the ground to the central core of the cricket ball. Angle of release of the ball was measured between the path of the ball and imaginary parallel line to the ground. Velocity of ball was measured by dividing distance i.e. the distance of 18.90 mt [20.12 mt (total length of the pitch) - 1.22 mt (Popping Crease)] between the two ends of cricket pitch, and the time taken by the ball to travel that distance. For measuring the performance of the subjects (Lateral deviation of the ball), point of the pitching of the ball was marked with the mark tool of Kinovea video analysis software and then video was played up to the point of crossing of the bowling crease by the ball, a perpendicular line was drawn from the ball to the bowling crease and perpendicular line was drawn from the previous line, from the point of pitching of the ball, it was calibrated with the stumps height, which provided lateral deviation of the ball.

2.5 Statistics

The data in the study was analyzed by using the following statistical techniques by using IBM SPSS 20. Descriptive analysis statistics was used for describing the data and nature of the data obtained on the samples of the study. Pearson's Product Moment Correlation was used for evaluating the various relationships of the selected variables towards the performance of spin bowling. Multiple Linear Regression was used for evaluating the contribution of identified biomechanical variables and construction of predictive model. A value of α = 0.05 was used for all tests as the criterion to determine the presence or absence of significance.

3. Results

To understand the nature of the data various statistics such as Range, Minimum, Maximum, Mean, Standard Deviation, Skewness, Kurtosis, Standard Error of Skewness (SES) and Standard Error of Kurtosis (SEK) has been calculated.

Table 1: Descriptive Statistics for evaluating the nature of the data

Variables	Range	Min.	Max.	Mean	S.D	Skewness	SES	Kurtosis	SEK
Height of Centre of Gravity	19.35	92.58	111.93	101.52	5.79	-.135	.427	-.877	.833
Angle of Release	3.00	7.00	10.00	7.73	0.91	1.171	.427	.728	.833
Height of Release	45.60	174.11	219.71	199.63	13.03	-.591	.427	-.637	.833
Average Velocity	3.97	12.04	16.01	13.84	1.04	.511	.427	-.592	.833
Ankle Joint right	28.00	99.00	127.00	107.43	8.34	1.363	.427	.456	.833
Knee Joint right	18.00	120.00	138.00	131.50	5.18	-.729	.427	-.377	.833
Hip Joint right	30.00	143.00	173.00	154.40	5.01	1.402	.427	6.275	.833
Shoulder joint Right	42.00	144.00	186.00	162.63	11.35	.249	.427	-.705	.833
Elbow joint Right	120.00	69.00	189.00	170.50	21.19	-3.988	.427	19.115	.833
Wrist Joint Right	58.00	138.00	196.00	164.40	16.13	.441	.427	-.584	.833
Ankle Joint left	24.00	119.00	143.00	128.63	6.14	.564	.427	.111	.833
Knee Joint left	45.00	146.00	191.00	171.77	12.65	-.285	.427	-1.123	.833
Hip Joint left	42.00	95.00	137.00	118.10	10.99	-.040	.427	-1.016	.833
Shoulder joint left	24.00	13.00	37.00	25.13	6.02	-.047	.427	-.348	.833
Elbow joint left	96.00	62.00	158.00	110.97	31.28	-.180	.427	-1.345	.833
Wrist Joint left	69.00	112.00	181.00	149.43	17.89	-.176	.427	-.899	.833

N=30

For testing the normality of the data (Table 1) skewness and kurtosis (descriptive statistics) has been performed. As a guideline, a skewness value more than twice its standard error indicates a departure from symmetry. Since maximum of the variables except the Angle of Release, Ankle Joint Right, Hip Joint Right and Elbow Joint Right skewness is lesser than twice its standard error, hence maximum of the variables were symmetrically distributed. Owing to this principle the Angle of Release, Ankle Joint Right, Hip Joint Right was positively skewed and Elbow Joint Right was negatively skewed as its value was more than twice its standard error. Thus, it can be interpreted that the performance of the subjects on Angle of Release, Ankle Joint Right, Hip Joint Right was more on the lower side and lower than the mean value. Thus, it can be interpreted that the performance of the subjects on Elbow Joint Right was more on the upper side and higher than the mean value. Similarly, as a guideline, kurtosis values more than twice its standard error indicates a significant kurtosis. Since maximum of the variables except the Hip Joint Right and Elbow Joint Right, kurtosis is lesser than twice its standard error, hence maximum of the variables have normal kurtosis. Owing to this principle the Hip Joint Right and Elbow Joint Right was leptokurtic as its value was positive. Thus, it can be interpreted that the performance of the subjects on Hip Joint Right and Elbow Joint Right was lightly spread and concentrated around the mode.

The scores of each of the identified kinematics variables of the off-spin bowlers were correlated with lateral deviation of the ball, in order to find out the relationship, which are depicted in Table 2.

Table 2: Product Moment Correlations of Kinematics Variables with Lateral Deviation of the Ball

Variables	Correlation Coefficient
Height of Center of Gravity	-.017
Angle of Release	.939*
Height of Release	-.072
Average Velocity	.955*
Ankle Joint right	.075
Knee Joint right	.143
Hip Joint right	-.207
Shoulder joint Right	.154
Elbow joint Right	.143
Wrist Joint Right	.331
Ankle Joint left	.661*
Knee Joint left	.446*
Hip Joint left	-.026
Shoulder joint left	.125
Elbow joint left	-.639*
Wrist Joint left	.247

* Correlation is significant at the 0.05 level. Significant value of the correlation coefficient at 0.05 level with 28 df = 0.361.

Table 2 reveals that the significance level for each of the correlation coefficients at 0.05 has been shown. Significance has been tested for two-tailed test. The correlation coefficient with mark (*) indicates that it is significant at 5% level. Angle of Release (r= 0.939), Average Velocity (r= 0.955), Ankle Joint Left (r=0.661), Knee Joint left (r= 0.446) and Elbow Joint left (r= -0.639) was significantly correlated to Lateral Deviation of Ball. Whereas no significant relationship was obtained between rests of the biomechanical variables to the performance of lateral deviation of the ball. Therefore it was evident that some kinematics variables did not show a significant relationship to lateral deviation of the ball and were less contributing to lateral deviation of the ball as shown in above. Out of all the variables which hold a significant relationship Angle of Release, Average Velocity, Ankle Joint Left and Knee Joint left are positive in nature and Elbow joint Right is negative in nature.

Multiple regression analysis was employed in order to predict the magnitude deviation of ball on the basis of identified kinematics variables.

Table 3: Model summary along with the values of R and R^2

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.955[a]	.912	.909	2.46287	.912	291.18*	1	28	.000
2	.980[b]	.960	.958	1.68332	.048	32.94*	1	27	.000
3	.984[c]	.968	.964	1.54336	.008	6.12*	1	26	.020
4	.987[d]	.974	.970	1.41602	.006	5.89*	1	25	.023

a. Predictors: (Constant), Average Velocity

b. Predictors: (Constant), Average Velocity, Elbow joint Right

c. Predictors: (Constant), Average Velocity, Elbow joint Right, Angle of Release

d. Predictors: (Constant), Average Velocity, Elbow joint Right, Angle of Release, Ankle Joint left

e. Dependent Variable: Lateral Deviation of Ball

N=30; *Significant at 0.05 level; $F_{.05} = 4.20$

Table 3 reveals that lateral deviation of ball on the basis of kinematics variables. Four regression models have been presented. In the fourth model, the value of R^2 is 0.974, which was maximum and, therefore, fourth model was used to develop the regression equation. The fourth model four independent variables, viz. Average Velocity, Elbow joint Right, Angle of release and Ankle joint left have been identified and therefore, the regression equation was developed based on these four variables only. Since R^2 value for this model was 0.974, therefore these four independent variables explain 97.4% variations in lateral deviation of ball.

Table 4: ANOVA Table showing F-values for all the Models

Model		Sum of Squares	Df	Mean Square	F	Sig.
1	Regression	1766.20	1	1766.20	291.18*	.000[b]
	Residual	169.84	28	6.07		
	Total	1936.04	29			
2	Regression	1859.53	2	929.77	328.12*	.000[c]
	Residual	76.51	27	2.83		
	Total	1936.04	29			
3	Regression	1874.11	3	624.70	262.26*	.000[d]
	Residual	61.93	26	2.38		
	Total	1936.04	29			
4	Regression	1885.91	4	471.48	235.14*	.000[e]
	Residual	50.13	25	2.01		
	Total	1936.04	29			

a. Dependent Variable: Lateral Deviation of Ball

b. Predictors: (Constant), Average Velocity

c. Predictors: (Constant), Average Velocity, Elbow joint Right

d. Predictors: (Constant), Average Velocity, Elbow joint Right, Angle of Release

e. Predictors: (Constant), Average Velocity, Elbow joint Right, Angle of Release, Ankle Joint left

N=30; *Significant at 0.05 level

Table 4 reveals that F-values for all the models have been shown. The F-value for the fourth model was highly significant; it concluded that the model selected was highly efficient also.

Table 5: Regression Coefficients of Kinematics variables to the performance on Lateral Deviation of Ball

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Correlations		
		B	Std. Error	Beta			Zero-order	Partial	Part
1	(Constant)	-81.70	6.10		-13.40	.000			
	Average Velocity	7.50	0.44	.955	17.06	.000	.955	.955	.955
2	(Constant)	-75.52	4.30		-17.55	.000			
	Average Velocity	8.17	0.32	1.041	25.34	.000	.955	.980	.970
	Elbow joint Right	-.09	0.02	-.236	-5.74	.000	.143	-.741	-.220
3	(Constant)	-69.51	4.63		-15.00	.000			
	Average Velocity	6.39	0.78	.815	8.24	.000	.955	.850	.289
	Elbow joint Right	-.08	0.02	-.200	-4.95	.000	.143	-.696	-.173
	Angle of Release	2.09	0.85	.233	2.47	.020	.939	.436	.087
4	(Constant)	-80.26	6.14		-13.07	.000			
	Average Velocity	6.03	0.73	.769	8.29	.000	.955	.856	.267
	Elbow joint Right	-.079	0.01	-.204	-5.49	.000	.143	-.739	-.177
	Angle of Release	1.95	0.78	.216	2.50	.020	.939	.447	.080
	Ankle Joint left	.133	0.06	.100	2.43	.023	.661	.437	.078

a. Dependent Variable: Lateral Deviation of Ball

Table 5 reveals that the unstandardized and standardized regression coefficient in all the four models. In the fourth model t-values for the entire four regression coefficient were significant as there significant values (p-values) were less than 0.05. Thus, it concluded that the variables; Average Velocity, Elbow joint Right, Angle of release and Ankle joint left significantly explains the variations in the lateral deviation of ball. *Regression Equation:* The unstandardized regression coefficients (*β*) of the second model shown in Table 5, the regression equation was developed which was: Lateral Deviation of ball = -80.26 – 6.03 X (Average Velocity) + -0.079 X (Elbow Joint Right) + 1.95 X (Angle of release) + 0.133 X (Ankle Joint Left)

4. Discussion

The objective of the present study was to identify the kinematic variables which are more significant to spinning the ball. Results revealed that some of the kinematic variables, such as Angle of Release, Average Velocity, Ankle Joint Left, Knee Joint left and Elbow Joint left were significantly correlated to ball deviation. The hypothesis as stated earlier that there may be significant relationship of identified kinematics variables to the performance of off-spin bowling and the identified biomechanical variables may significant contributors of off-spin bowling. Hypothesis is accepted for Angle of Release, Average Velocity, Elbow Joint Right, Hip Joint Left and Shoulder joint left and may not be accepted for other kinematics variables. In off-spin bowling the regression equation was reliable as the value of R^2 was 0.974. The four variables selected in that regression equation explain 97.4% of the total variability in lateral deviation of ball was good. Since F-value for that regression model was also highly significant, the model was reliable. At the same time all the regression coefficient in that model were highly significant and therefore all the two variables selected in the model viz. Average Velocity, Elbow joint Right, Angle of release and Ankle joint left were valid in estimating the lateral deviation of ball of a off spin bowling. The findings of the study showed that four kinematic variables (Average Velocity, Elbow Joint Right, Angle of Release and Ankle Joint Left) significantly predicted the lateral deviation of the ball of off-spin. Therefore, the hypothesis as stated earlier is accepted.

Mean and standard deviation of subjects angle of release 7.73±0.91, range is 3.00, its shows that the lower angle of release as a significant contribution to ball deviation. The ideal release angle may depend on the technique and physical attributes of the cricketers. At the time of release elbow should be approaching full extension, to make sure that this joint has made a full contribution to the flight of the ball. This finding is in agreement with others viz. Chin *etal*., 2009[10], linked lower elevation angles at ball release in finger-spin bowlers to increased levels of top-spin when delivering their stock delivery. Range of elbow joint angle (r) is 120 degrees and its help to the bowler influences the average velocity of the ball. Flexion at the elbow joint is required for upper arm internal rotation at the shoulder to play a significant role in velocity generation (Marshall &Ferdinands, 2002)[25]. Chin *et al*., 2009[10], reported that forearm abduction and fixed elbow flexion in the bowling arm were higher for the elite players. The approach velocity of the bowler influences the release velocity of the ball (Stockill*et al*., 1993)[31]. Aginsky&Noakes, 2008[1], suggested that the elbow joint rotates about 90 degrees as a result of humeral rotation during the movement of shoulder circumduction produced by the bowler's delivery action. This causes the plane in which the elbow joint moves to change throughout the delivery action. The bowling arm follows a close to normal swing pattern similar to that of sprinting until the point of back foot strike, also reported that the initiation phase of upper arm circumduction starts at the hip joint with the elbow fully extended or at a constant angle (Bartlett *et al*., 1995)[4]. The initiation phase of upper arm circumduction occurs between back foot and front foot strike; the upper arm should be close to vertical with an angle of 200 degrees in relation to the trunk (Elliott *et al*., 1989)[14]. Some studies suggest that the arm should be a little bit in front of the vertical line with an angle of close to160 degrees (Davis *et al*., 1976) [12]. There is no one preferred spin direction in spin bowling. Foster *et al*. (1989) [19] reported that an increased knee and hip angles were identified as contributing to the increased height of release. In contrast, if height of release increase then its produce top-spin on the ball and less deviation off the pitch but gain the advantage of producing more drops in flight, a factor that can cause the batsman to misjudge the flight of the ball. Higher components of side-spin potentially create more deviation off the pitch. Average Velocity mean and standard deviation of subjects is

13.84±1.04, revealed that the ball velocity of the off-spin bowlers is low, because they are not an elite level players. The high performance off-spin bowlers delivered the bowl with velocities above 18.1 m.s- 1, while those in the low performance group produced velocities less than 17.2 m.s-1. This is consistent with the studies of Justham *et al*., 2008[22], and Chin *et al*., 2009[10], both finding that the ball velocities of off-spinners were faster in the higher performance levels. This is consistent with the studies of Justham *etal*., 2010[23], for spin bowling, the speed of the ball at release, vertical release angle, and deviation angle after pitching varied for different delivery types, the pitching line of the ball became closer to the centre stump as the delivery length became fuller and the ball release angle became flatter towards the horizontal.

5. Conclusions

Off-spin bowling is a complex and highly dynamic sporting movement. Considering the purpose along with objectives of the study, based on the analysis and within the limitations of present investigation, conclusions derived. This study attempted to identify the mechanics that influence on ball deviation a bowler of university level. Furthermore, the selected average values of different identified variables had contribution at the time of spin bowling (at the time of release). Result of the minimum and maximum scores was provided a boundary of identified variable scores at the time of spin bowling. The biomechanical variables namely Angle of Release, Average Velocity, Ankle Joint Left, Knee Joint left, Shoulder joint left and Elbow Joint left was found significantly related with the lateral deviation of ball in off-spin bowling. Average Velocity, Elbow joint Right, Angle of Release and Ankle joint left were valid in estimating the lateral deviation of ball of an off-spin bowling. The various models developed in the present study helps the professionals for predicting the lateral deviation of the ball in off-spin bowling. It will be important to standardize terminology and to agree on reporting conventions, once new biomechanical knowledge is gained, it is the responsibility of the research community to present it to cricketers in an understandable manner.

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