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# Lead knee extension contributes to drag-flick performance in field hockey

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## ABSTRACT

Understanding the biomechanics of the drag-flick is important for refining the performance of this task in field hockey. The aim of this study was to determine whether the maximal knee angle and maximal angular velocity of the lead knee extension are associated with ball speed in elite drag-flick players. The kinematics of the drag flick was studied in 19 elite field-hockey players who performed 15 drag-flick shots each towards a target located 1.30 m high at optimal speed. A motion capture suit was used to capture full body drag-flick behaviour sampling at 240 Hz. Multiple regression analyses were used to study the association between both the maximal knee flexion angle and maximal angular velocity of the leading knee extension and ball speed. Significant positive associations were found between knee extension velocity and ball speed ( $R^2 = .127$ ,  $p < .001$ ). A higher knee extension velocity resulted in higher ball speeds within the individual, without negatively affecting the accuracy. It is advised to train, within an elite drag-flick group, for higher knee extension speed to improve the drag-flick performance. Whether training to improve this parameter results in higher ball speeds should be subject of future studies.

## ARTICLE HISTORY

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Hockey; kinematics; knee; speed; elite; biomechanics

## 1. Introduction

The drag-flick is a highly relevant skill to enlarge scoring opportunities during penalty corners (Piñeiro, Sampedro, & Refoye, 2007) in field hockey. This technique is a complex variation of the “simple flick” whereby the ball is picked up from behind the body, allowing more “wind-up” of the body to store potential energy. Both the ball accelerating while it is dragged along the ground and the stick moving

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in a forceful “slinging” action result in launching the ball from the stick with high speed towards the goal (Kerr & Ness, 2006; Piñeiro et al., 2007).

The technique of the drag-flick is best described as a coordinated sequence of body movement and muscle actions aiming to reach the maximal speed of the stick head at ball release (Ibrahim, Faber, Kingma, & Van Dieën, 2016). The drag-flick is divided into several key events (see Figure 1); T1 – T6 are key events on initial ground contact of each step. After T5 the lead knee will flex until maximal knee flexion (MKF) is reached, followed by extension. Higher ball speeds result in less time for the goal-keeper to anticipate (Eskiyecek, Meriç Bingül, Bulgan, & Aydin, 2017).

It is generally accepted that the interaction of body segments transfers energy due to the proximal to distal kinematic sequence, finally resulting in high speed of the most distal segment (Ibrahim et al., 2016; López de Subijana, Juarez, Mallo, & Navarro, 2010). A proximal to distal whipping action was confirmed present in elite field-hockey players (López de Subijana et al., 2010). Previous studies on the execution of the drag-flick identified a large distance between both feet (stance width) at T5 (McLaughlin, 1997). Skilled players show a smaller knee flexion angle at T5 and a smaller angular change compared to less skilled drag-flickers (López de Subijana et al., 2010). Additionally, trunk axial rotation and lateral flexion towards the target, right wrist palmar flexion and left wrist extension were the main contributors to the stick endpoint velocity (Ibrahim et al., 2016). Studies on the influence of the lower extremities on the drag-flick performance are lacking in hockey, but the relation of support leg action with ball speed in football and baseball was demonstrated previously (Augustus, Mundy, & Smith, 2007; Inoue, Nunome, Sterzing, Shinkai, & Ikegami, 2014; van Trigt, Schallig, van der Graaff, Hoozemans, & Veeger, 2018).

Understanding the biomechanics of a drag-flick may guide monitoring the training process aiming to improve the performance of this specific task (Augustus et al., 2007). The relation between action of the leading knee and ball speed when established provides new knowledge for coaches and players to be used for improved performance of the drag-flick. Therefore, the aim of this study was to determine whether the maximal knee angle and maximal angular velocity of the lead knee extension are associated with ball speed in elite drag-flick players. It was hypothesised that a smaller maximal knee angle and higher maximal knee extension velocities have a positive association with ball speed.

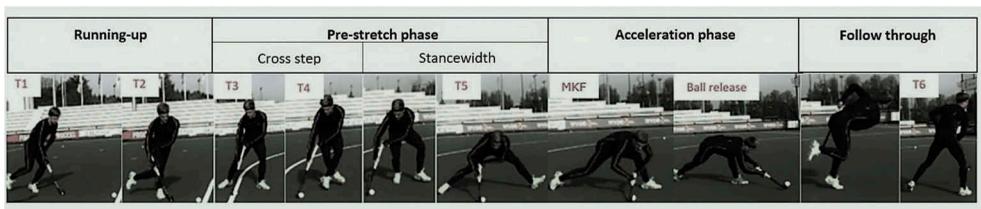


Figure 1. All key events presented from the beginning to the end of execution of the drag-flick.

## 2. Methods

### 2.1. Participants

Thirty-one elite field-hockey players were invited for this study. Ten of them did not participate due to injury or could not make it to the measuring day because of other obligations. Twenty-one players completed the drag-flick tasks. Data of two players could not be used for analysis due to data collection errors. Finally, 19 elite field-hockey players, age 19.11 (4.10) years, body length 1.80 (8.21) m, were included in this study. Participants were all drag-flick specialists from the selection teams of the Dutch Hockey Federation (KNHB). This includes the Dutch National Teams and national teams from different age groups. The drag-flick trainers scheduled all the drag-flick specialists for the measuring day and informed them about the research.

Personal data of the four groups are shown in [Table 1](#). It should be noted that the groups were classified on gender and age groups (junior/senior).

Players signed an informed consent prior to participation in this study. The Scientific and Ethical Review Board (VCWE) of the Faculty of Behavior & Movement Sciences, VU University Amsterdam, approved the research protocol and confirmed no medical ethical approval was needed for this study prior to the measurements.

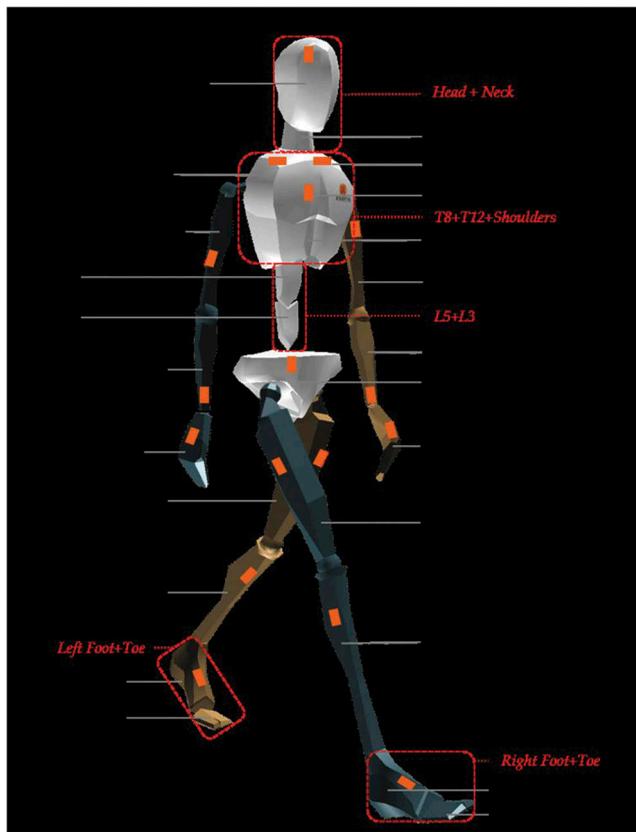
### 2.2. Measures

The 3D analyses of the drag-flick were performed at the site of hockeyclub Kampong, Utrecht, The Netherlands. The kinematic data were recorded using a motion capture suit (Xsense Technologies B.V., Enschede, The Netherlands) at 240 Hz. This system was validated against a Vicon motion analysis system for the lower extremity and pelvis kinematics during high-velocity movements in sport-specific settings (Blair, Duthie, Robertson, Hopkins, & Ball, 2018). It is composed of 17 inertial motion sensors, placed on a tight-fitting Lycra suit, allowing this system to be used on the pitch (Dinu et al., 2016). Sensors were mounted on the following segments: head, sternum, pelvis, upper legs, lower legs, feet, shoulders, upper arms, forearms and hand ([Figure 2](#)). Xsens MVN estimates the orientation of segments by combining the orientations of individual sensors with a biomechanical model of the human body. The orientation of each sensor

**Table 1.** Anthropometric parameters presented as mean (SD) of the total sample and per gender (female and male) and age category (juniors <18 years and seniors ≥8 years old).

Participants	Female n, (%)	Male n, (%)	Total n, (%)
Total n, (%)	7 (37%)	12 (63%)	19 (100)
Junior	5 (62%)	3 (38%)	8 (42%)
Senior	2 (18%)	9 (82%)	11 (58%)
Age (yrs)			
Total	16.57 (2.06)	20.58 (4.27)	19.11 (4.10)
Junior	15.40 (1.02)	16.33 (0.94)	15.75 (1.09)
Senior	19.50 (0.50)	22.00 (4.00)	21.55 (3.75)
Height (m)			
Total	1.71 (4.19)	1.84 (6.44)	1.80 (8.21)
Junior	1.70 (4.32)	1.83 (4.78)	1.75 (7.63)
Senior	1.75 (1.00)	1.84 (6.88)	1.82 (7.20)

Abbreviations: SD = standard deviation; n = number; yrs = years; m = meter.



**Figure 2.** The definition of the 23 segments in the kinematic model of Xsens MVN.

is obtained by fusing accelerometer, gyroscope and magnetometer signals using an extended Kalman filter. Measurements of segment heights were used to calibrate the system using a steady upright position. Steadiness of the subject and the homogeneity of magnetic field around the sensors determined the calibration (Karatsidis et al., 2017).

A receiver on the body during the movement interconnects multiple strings of the sensors and retrieves their data ensuring exactly synchronised samples. The collected data is transmitted by a spread spectrum wireless link to an access point connected to the PC. Raw data were on all angles, angular velocity and accelerations were then entered in a MVN 2018 software package to retrieve for further analysis.

### **2.3. Set-up**

The situation of a penalty corner was mimicked but without goalkeeper or defenders with the ball positioned on the circle line, 14.63 m of the target (Figure 3). This target was placed 1.30 m above the ground as this height is considered to be the most preferred for drag-flicks in game situations (Ibrahim et al., 2016). The target was placed in the middle of the goal, so none of the participants had any advantage. The target had rings similar to a dartboard. Most points were earned hitting the bull whilst fewer

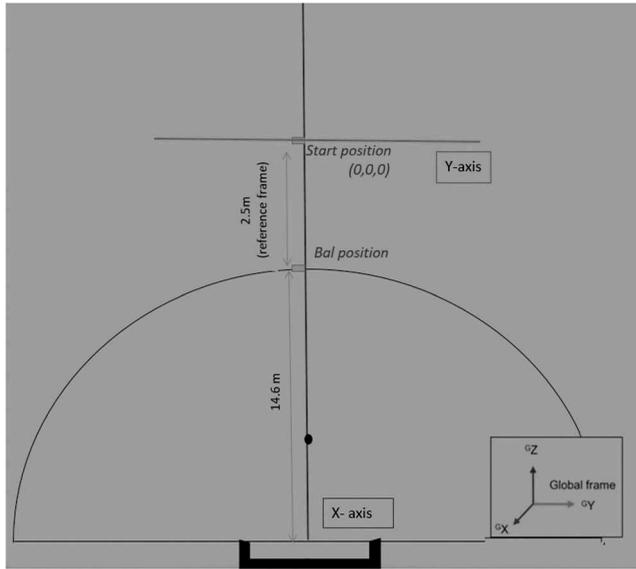


Figure 3. Measurement set-up.

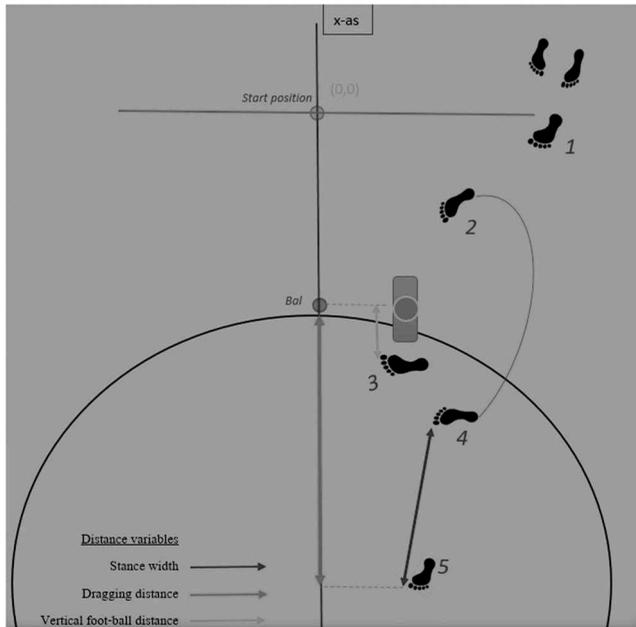
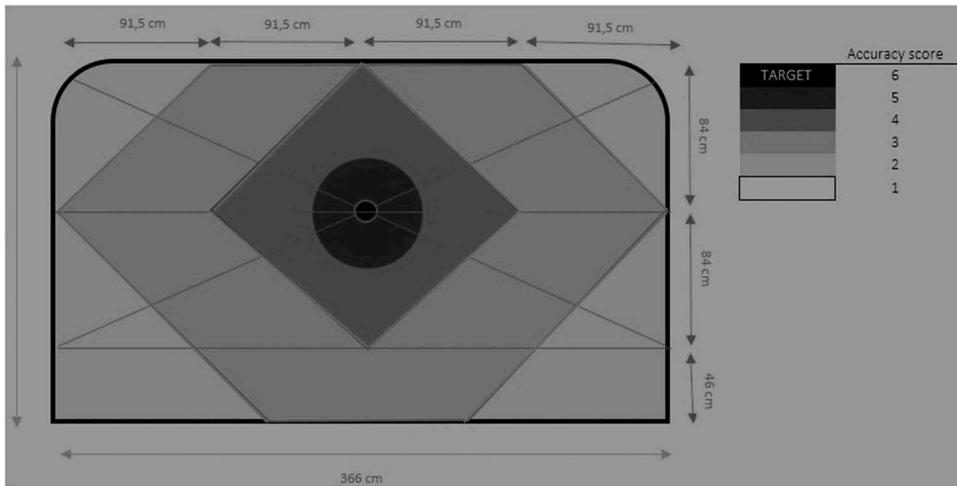


Figure 4. Target setup.

points were awarded for hitting the outside rings (Figure 4). These data were recorded by the ball that hit the target, in case of doubt the score could be checked by video. This was referred to as the accuracy score. The ball speed was measured with a radar gun (Bushnell velocity speed radar gun 101,911, Buschnell, Kansas City, Missouri, United States of America) from a static position on the right side of the drag-flicker. The cosine



**Figure 5.** numbered steps of the drag-flick.

effect is minimised to measure as close as possible in line with the ball. The quality score was calculated with the equation: (ball speed-30) \* accuracy score.

Fifteen drag-flick trials were captured per player at the player's optimal speed towards the target. So, a total of 285 drag-flicks were available for analysis. Players used their own stick. The ball used was a Kookaburra dimple elite ball, the most commonly used hockey ball during national and international top hockey games (Kookaburra Dimple Elite, Kookaburra, Moorabbin, Victoria, Australia).

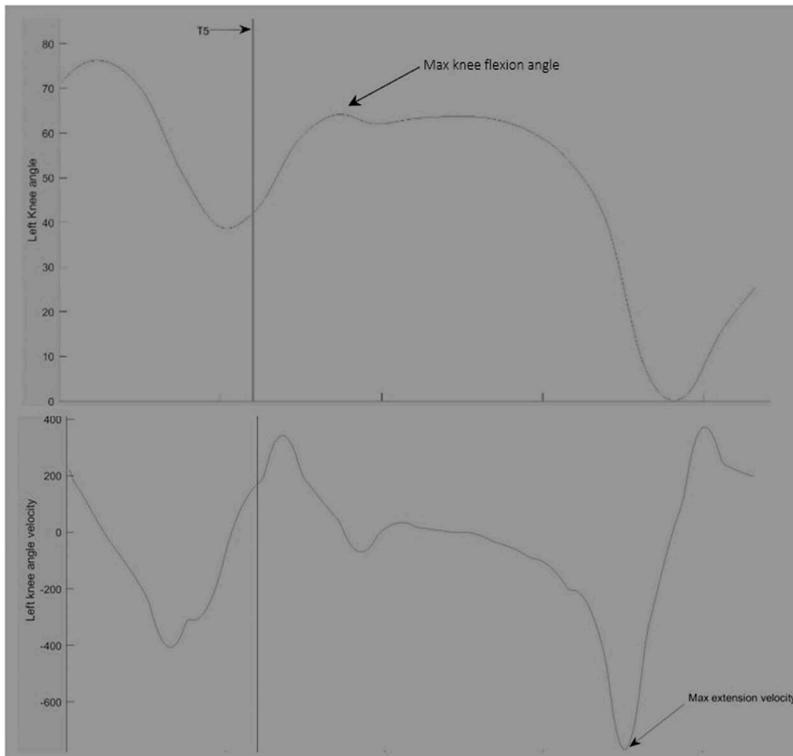
The stance width was calculated by the distance (cm) between the trailing (step 4) and leading (step 5) toe. The dragging distance was the distance (cm) between the starting position of the ball and the leading toe (step 5). Furthermore, the foot-ball distance referred to the distance (cm) between the ball and the left foot (step 3). All the above-mentioned distance variables are presented in [Figure 5](#).

Knee angles were defined as the smallest angle (°) between the vector through the lower leg and upper leg. A higher knee angle value indicated a more flexed knee. The maximum knee angle was defined as the highest knee angle after the key event of step 5 ([Figure 6A](#)). The maximal angular velocity (°/s) of lead knee extension is defined by the lowest peak velocity after T5 ([Figure 6B](#)).

## **2.4. Statistical analysis**

Statistical analysis was performed using SPSS v.25 (IBM, Armonk, USA) software. The average values of performance and movement variables of each participant were calculated using descriptives. Normality of the data was assessed with the Shapiro Wilk test.

The study of López de Subijana et al. (2010) found significantly higher ball velocities, stance widths and longer dragging distances in male drag-flickers compared to the females. So, gender is expected to be as a confounding factor within this study. Furthermore, for less mature hockey players, who would presumably have – on



**Figure 6.** **A.** Knee angle in time (T4-T6), reflecting the maximal knee flexion angle. **B.** Knee angle velocity in time (T4-T6), reflecting maximal angular velocity of lead knee extension.

average – less strength and less experience (Kerr & Ness, 2006), a different movement pattern is expected compared with mature hockey players. Therefore, statistical corrections would be made for gender (male/female) and age (junior/senior) groups.

Parametrical independent sample T-test statistics were used to study the differences between variables of the female and male, and junior (age<18) and senior (age≥18) groups.

To study associations between the individual’s maximum knee flexion angle and maximal angular velocity of lead knee extension and ball speed, the following models were used:

$$\text{Ball speed} = a + \text{individual} * b + \text{maximum knee angle} * c \quad (\text{model 1})$$

$$\text{Ball speed} = a + \text{individual} * b + \text{maximum knee extension velocity} * c \quad (\text{model 2})$$

\* a, b, c are the constant values.

\*\*  $p < 0.05$  indicate significant differences.

Because of the fact that every individual did multiple trials, the models included the variable “individual”, the different trials of the same individual, to look within each individual.

For each model, the coefficient for multiple determination of multiple regression, the  $R^2$ , was calculated to indicate the percentages of the performance outcomes being determined

by the predictors. Multiple regression allowed to determine the significant contribution of each of the predictors to the total variance. Within this study, this value was used to check if the movement variable significantly contributed to the performance outcome. A residue analysis was performed for each regression model to check if the residues were normally distributed, homoscedastic and linear.

### 3. Results

The means and standard deviations of the calculated kinematic variables are presented in Table 2, separated for gender and age groups, along with levels of significance ( $p$  values) relating to differences between groups. The male group had a significantly higher quality score ( $37.62 \pm 1.64$  vs  $26.22 \pm 0.56$ ,  $t(13.371) = -6.563$ ;  $p < .001$ ), ball speed ( $25.62 \pm 2.18$  vs  $19.50 \pm 2.18$  m/s,  $t(15.495) = -8.667$ ;  $p < .001$ ), running speed ( $3.77 \pm 0.20$  vs  $3.48 \pm 0.13$ ,  $t(17) = -3.434$ ;  $p = .003$ ), longer body length ( $171.86 \pm 4.53$  vs  $184.08 \pm 6.72$ ,  $t(17) = -4.258$ ;  $p < .001$ ), stance width ( $168.14 \pm 7.68$  vs  $157.87 \pm 7.16$ ,  $t(17) = -2.878$ ;  $p = .011$ ), dragging distance ( $273.37 \pm 222.42$ ,  $t(17) = -3.968$ ;  $p < .001$ ), relative dragging distance ( $1.49 \pm 0.18$  vs  $1.30 \pm 0.10$ ,  $p = .020$ ) and foot-ball distance ( $43.28 \pm 35.94$  vs  $8.44 \pm 18.97$ ,  $t(17) = -2.361$ ;  $p = .030$ ) compared with the female group. Furthermore, the senior group had a higher quality ( $36.42 \pm 2.23$  vs  $29.29 \pm 1.71$ ,  $t(16.890) = -2.538$ ;  $p = .030$ ) and ball speed ( $90.64 \pm 11.70$  vs  $75.20 \pm 7.61$ ,  $t(17) = -3.282$ ;  $p = .005$ ) compared with the junior group. There were no significant differences in movement variables between the senior and junior groups.

In Table 3 the regression analyses results are summarised. For each maximal knee flexion angle and maximal angular velocity of lead knee extension, the relationship with ball speed and accuracy was assessed, corrected for the individual effect. Maximal angular velocity of lead knee extension significantly predicted the ball speed (model 2). The multiple regression analyses between maximum knee flexion angle, individual and ball speed was significant, but the maximum knee angle was not found to significantly contribute to ball speed within this model (model 1).

**Table 2.** Kinematic variables for gender and age groups presented as mean (SD).

Variables	Gender			Age		
	Female (n = 7)	Male (n = 12)	$p$ value	Junior (n = 8)	Senior (n = 11)	$P$ value
Quality	26.22 (0.56)	37.62 (1.64)	.000**	29.29 (1.71)	36.42 (2.23)	.030*
Ball speed (m/s)	19.50 (2.18)	25.62 (2.18)	.000**	20.87 (2.08)	25.18 (3.25)	.004*
Accuracy	2.85 (0.40)	3.16 (0.40)	.118	2.88 (0.28)	3.17 (0.45)	.144
Body length (cm)	171.86 (4.53)	184.08 (6.72)	.000**	175.38 (8.16)	182.64 (7.55)	.062
Stance width (cm)	157.87 (7.16)	168.14 (7.68)	.011*	161.76 (9.10)	166.24 (8.66)	.290
Drag distance (cm)	222.42 (14.78)	273.37 (31.81)	.000**	250.61 (45.89)	257.50 (29.92)	.697
Foot-ball distance (cm)	8.44 (18.97)	43.28 (35.94)	.030*	27.24 (39.94)	32.769 (32.29)	.718
Running speed (m/s)	3.48 (0.13)	3.77 (0.20)	.003*	3.64 (0.15)	3.68 (0.27)	.711
Maximum flexion angle	65.11 (7.18)	62.92 (11.99)	.668	60.29 (12.50)	66.22 (8.09)	.225
Maximum angular velocity lead knee extension ( $^{\circ}$ /s)	291.36 (99.66)	341.75 (66.99)	.264	308.43 (89.83)	333.91 (89.83)	.518

Abbreviations: SD = standard deviation; n = number; m = meter; s = second; Max = maximal; \* =  $p < 0.05$ ; \*\* =  $p < 0.001$  indicate significant differences between groups

**Table 3.** Intra-individual regression analyses between movement variables (maximal extension velocity and maximal knee angle) and performance outcomes (ball speed, accuracy). \*( $p < 0.05$ ) and \*\* ( $p < 0.001$ ).

Movement variables	Performance outcomes	$R^b$	$p$ value
Maximum knee angle	Ball speed	.082 <sup>a</sup>	.000
	Accuracy	.000	.931
Maximum extension velocity	Ball speed	.127 <sup>b</sup>	.000**
	Accuracy	.001	.880

<sup>a</sup>Ball speed = 81.574 (<.001\*\*) + individual \* .430 ( $p < .001$ \*\*) + maximum knee angle \* -.068 ( $p = .274$ )

<sup>b</sup>Ball speed = 70.824 (<.001\*\*) + individual \* .418 ( $p < .001$ \*\*) + maximum extension velocity \* .021 ( $p < .001$ \*\*)

**Table 4.** Intra-individual correlations and regression analyses between movement variables and performance outcomes (ball speed, accuracy and quality) from model 1. \*( $p < 0.05$ ) and \*\* ( $p < 0.001$ ).

	Movement variables	$R$ -score	$p$ value
Ball speed	Stance width	.433	.000**
	Dragging distance	.420	.000**
	Foot-ball distance	.312	.000**
	Running speed	.482	.000**

Table 4 presents the associations between movement variables and ball speed, corrected for the effect of the individual, indicated as the  $R$ -score from the partial correlations.

#### 4. Discussion and implications

The aim of this study was to determine whether the maximal knee angle and maximal angular velocity of the lead knee extension is associated with ball speed in elite drag-flick players. A higher maximal angular velocity of lead knee extension results in higher ball speeds. Thus far, no research on the angular velocity of the leading knee joint during the drag-flick in relation to ball speed existed.

Rosalie et al. (2018) studied the lower limb kinematics of the drag-flick compared with the normal “hit”. The peak left knee flexion angle (57.1) was lower compared with this study (63.72).

Previous research studied knee extension movement of the support leg during pitching techniques of elite youth baseball players (van Trigt et al., 2018) and during the maximal instep kick with soccer (Augustus et al., 2007; Inoue et al., 2014). Some analogies seem to exist based on kinematic principles. Within the pitching technique of elite youth baseball pitchers, more extended knee angles of the leading leg prior to ball release were significantly associated with higher ball speeds. The leading leg receives external ground reaction forces resulting in a braking effect during the stance phase. This allows the proximal segments to rotate over the leading leg, being a stable platform (van Trigt et al., 2018). This interaction of body segments sequentially transfers energy from the ground upward to the upper extremity, finally resulting in ball speed (van Trigt et al., 2018). Augustus et al. (2007) found vertical displacements to be significantly correlated with ball velocity. Regarding the football instep kick, pronounced extension

of the support leg within the knee and hip, inducing vertical displacement of the pelvis and hips during kicking resulted in enhanced ball speed. Vertical displacement or “hip lift” induces a passive knee extension velocity of the kicking leg through intersegmental dynamics (Zajac, Neptune, & Kautz, 2002).

The ball velocities obtained in this study were larger than those of the male (21.9 m/s) and female (17.9 m/s) group reported by López de Subijana et al. (2010) and those (19.1 to 21.9 m/s) reported by McLaughlin (1997). The international skilled drag-flicker within the study of López de Subijana et al. (2010) dragged at comparable speeds (25.4m/s) compared to the men’s group of this study.

The drag-flick stance widths were larger than 1.23 m (for the group) and 1.42 m (for the model flicker) reported by McLaughlin (1997), and 1.49 m (model drag-flicker), 1.55 (male group) and 1.32 (female group) reported by López de Subijana et al. (2010). The drag-flick distances in the present study were longer than those of McLaughlin (1997) (1.36 for the group and 1.47 for de model drag-flicker) and López de Subijana et al. (2010) (2.01 for model, 2.42 male, 1.70 female).

This study has its limitations. The target placed in the middle of the goal may have affected the accuracy score. Participants may have experienced this as a difficulty because they were trained to drag the ball in the corners of the goal. Playing the ball exactly in the middle may have resulted in a different movement pattern and therefore have caused more variation in the accuracy instead of flicking in the corners of the goal, which is a more game-related situation. The test set-up without goalkeeper and defenders being present may have resulted in less experienced time pressure to perform the drag-flick task. Whether or not this was the case and how this may have affected the results found remains unknown. Although the main limitation of the present study was the number of participants. For future studies, a higher sample size is recommended to enhance the power of the study.

Future studies should focus on an intervention study were the drag-flick players improve the extension velocity to indicate if this will achieve higher performance outcomes.

The sequence of timing of the peak knee extension velocity should be related to the other joints. Previous studies documented the sequence of peak segments of the drag-flick, but that was only for the upper body (Ibrahim et al., 2016; López de Subijana et al., 2010). Also, the extension angle at ball release is interesting for future studies.

## 5. Conclusion

In summary, maximal angular velocity of the lead knee extension is associated with higher ball speeds in the present sample of national drag-flick specialists. Based on this study within elite drag-flick players, it is advised to train for higher extension speed to improve the drag-flick performance; however, a more profound study to the effects of training the knee extension velocity is recommended.

## Disclosure statement

No potential conflict of interest was reported by the authors.

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