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THE STEPS NEEDED TO PERFORM ACCELERATION AND TURNING AT DIFFERENT APPROACH SPEEDS

KORAKI POTREBNI ZA IZVEDBO POSPEŠEVANJA IN ZAVIJANJA IZ RAZLIČNIH ZAČETNIH HITROSTI

ABSTRACT

The aims of the study were to examine: how many and which steps are needed to initiate and complete accelerations and turnings at different angles at different approach speeds; and how an intended turning angle and approach speed influence the magnitude of the actual turning angle in each step. Eight soccer players participated in the study. They performed acceleration and turnings: 1) from a standstill; 2) while already jogging; and 3) while already running on an outdoor soccer field. The speeds and angles were calculated from the data obtained from the high-end Global Navigation Satellite System. The high correlation between the intended turning angle and actual turning angle indicated the major turning steps during a turn. The intended turning angle revealed a large effect on the magnitude of the turning angle during the side-step ($r = 0.995$, $p < 0.01$) and the following step ($r = 0.950$, $p < 0.01$) for acceleration and turning from a standstill, and during the first two steps following the side-step for starts made while already jogging ($r= 0.919$, $p < 0.01$; $r = 0.952$, $p < 0.01$) and running ($r = 0.897$, $p < 0.01$; $r = 0.881$, $p < 0.01$). Further, a major part of the turning began earlier at a lower approach speed, which allowed the turning to be more quickly completed. In conclusion, the effect of acceleration with turning on the turning angle could already be seen two steps before and up to two steps after the major turning steps during a turn.

Keywords: angle, GNSS, GPS, kinematics, soccer

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POVZETEK

Cilji raziskave so bili raziskati: 1) koliko korakov je potrebnih za začetek in zaključek pospeševanja in zavijanja v različne smeri iz različnih začetnih hitrosti in 2) kako sprememba smeri za nameravan kot in začetna hitrost vplivata na velikost dejanske spremembe smeri v posameznem koraku. V raziskavi je sodelovalo osem nogometašev. Iz mirovanja, počasnega teka in srednje hitrega teka so pospeševali in zavijali na nogometnem igrišču z naravno travo. Hitrosti in koti so bili izračunani s pomočjo tehnično dovršenega globalnega navigacijskega satelitskega sistema. Velika povezanost med nameravano spremembo smeri gibanja in dejansko spremembo smeri gibanja je pokazala na najbolj pomembne korake med zavijanjem. Nameravana sprememba smeri gibanja je vplivala na velikost spremembe smeri med korakom v stran ($r = 0.995$, $p < 0.01$) in med sledečim korakom ($r = 0.950$, $p < 0.01$) pri pospeševanju in zavijanju iz mirovanja in med prvima dvema korakoma, ki sledita koraku v stran pri začetkih iz počasnega teka ($r= 0.919$, $p < 0.01$; $r = 0.952$, $p < 0.01$) in srednje hitrega teka ($r = 0.897$, $p < 0.01$; $r = 0.881$, $p < 0.01$). Poleg tega se je začel glavni del zavijanja prej pri manjših začetnih hitrostih, kar je prispevalo k hitrejšemu zaključku zavijanja. Glede na dobljene rezultate lahko zaključimo, da so se učinki pospeševanja in zavijanja pokazali v spremembi smeri gibanja dva koraka pred in dva koraka po najbolj pomembnih korakih.

Ključne besede: GNSS, GPS, kinematika, kot, nogomet

INTRODUCTION

Many sports such as different football codes require athletes to accelerate, decelerate and turn throughout the game (Docherty, Wenger, & Neary, 1988; Sheppard & Young, 2006). These bursts of maximal effort tend to be concentrated around crucial match actions such as making a break away from the opposition or during a tackle (M. Buchheit, Bishop, Haydar, Nakamura, & Ahmaidi, 2010; Medendorp, Van Gisbergen, & Gielen, 2002; Rienzi, Drust, Reilly, Carter, & Martin, 2000).

Acceleration is essential for a successful performance in soccer (Baker & Nance, 1999; Deutsch, Kearney, & Rehrer, 2002; Douge, 1988; Grasso, Glasauer, Takei, & Berthoz, 1996) and is potentially decisive in determining the outcome of a game (Cometti, Maffiuletti, Pousson, Chatard, & Maffulli, 2001; Rienzi et al., 2000; Sayers, 2000). In particular, quickness in the first few steps of a sprint is viewed as being vitally important during a game (Patla, Adkin, & Ballard, 1999). In addition, players rarely cover large enough distances when sprinting to reach top speed (Douge, 1988; Reilly, 1997; Reilly & Borrie, 1992). One reason for not being able to reach maximum speeds is turning, which has been proven to decrease the top speed of running (Chang & Kram, 2007).

Soccer players perform less than half of their purposeful movements in a forward direction; they perform different types of movement with a range of intensities and frequently turn during movement patterns (Bloomfield, Polman, & O'Donoghue, 2007; Docherty et al., 1988).

Players often initiate sprints when already moving at moderate speeds (Young, Benton, Duthie, & Pryor, 2001). A gait transition will occur when accelerating from one running speed to another. Human gait transitions are mainly realised in a single transition step when running straight forward (Segers, Lenoir, Aerts, & De Clercq, 2007; Sheppard & Young, 2006). However, in ball games accelerations from one speed to another are often accompanied by turning. In such situations, gait transitions sometimes require several steps before completion (Ohtsuki, Yanase, & Aoki, 1987).

Previous studies focused on the sprint time needed to complete different running courses with a change in direction and revealed that the greater the angle of change in direction, the greater the sprint time (M. Buchheit et al., 2010; Martin Buchheit, Haydar, & Ahmaidi, 2012; Young, Hawken, & McDonald, 1996) because during curve sprinting the inside leg generates smaller peak force compared to the outside leg (Chang & Kram, 2007). A study of changing direction at a constant speed of 3 m/s and a change in direction of 60° showed that at least one step is required to stabilise the body following a turn (Patla et al., 1999). To our knowledge, no study has investigated turning angles through steps made during acceleration with turning at different angles and at different approach running speeds and none has investigated the initiation and completion of a change in direction regarding the turning angle. The outcome is that we cannot fully understand or define the movement of soccer players or players in other sports where acceleration and turning occurs.

Therefore, the aims of the study were to examine: 1) how many and which steps are needed to initiate and complete accelerations and turnings at different angles at different approach speeds; and 2) how the intended turning angle or approach speed influence the magnitude of the actual turning angle in each step on a natural playing field and using soccer studs.

MATERIALS AND METHODS

Participants

Eight soccer players from the 2nd Slovenian soccer league voluntarily agreed to participate in the study and provided their written informed consent. The participants were 20.5 ± 2.1 years old, their height 179 ± 5.8 cm and their weight 76.3 ± 4.8 kg. Measurements were approved by the regional Ethics Committee of the Faculty of Sports, University of Ljubljana in Slovenia and were managed in accordance with the Helsinki Declaration.

Experimental protocol

The measurements were performed on a natural grass soccer field. Dressed in full soccer equipment, the participants accelerated straightforward and accelerated whilst turning at angles of 30°, 60° (Figure 1), 90°, 120°, 150° and 180° (Figure 2) according to the initial direction of movement from a standstill, and at two different gradually faster and controlled approach speeds to a distance of 10 m. The starts from a standstill were performed from a defensive stance characterised by the feet being placed parallel to each other and the legs slightly flexed at the ankles, knees and hips. The weight of the body was centred between the left and right balls of the feet. The participants progressed by leaning their body down and placing the push-off leg in the opposite direction. From flying starts the side step cut, in which direction is changed by planting one foot to the opposite direction, was also used. Two different approach speeds for the flying starts were required from the soccer players: one while already jogging (running at a gentle pace of ~10 km/h) and the other while already running (~15 km/h).

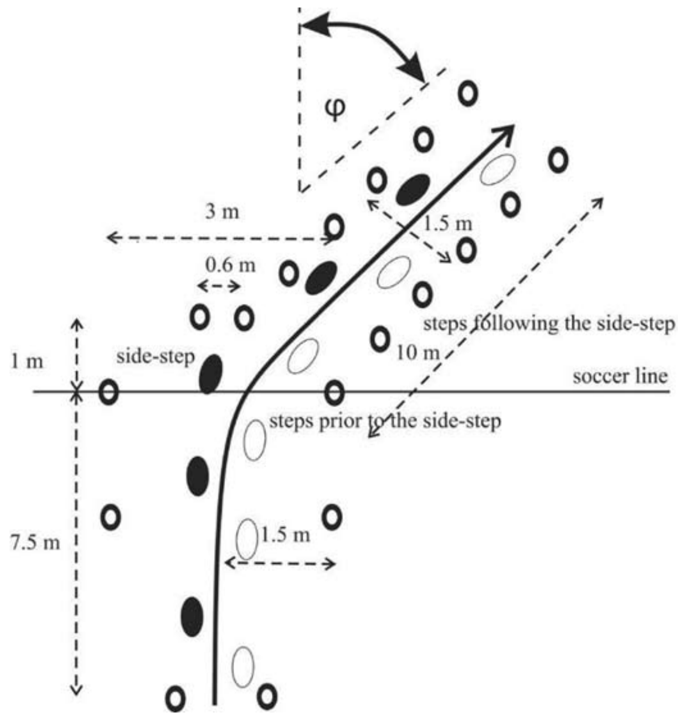

Figure 1: Polygon from agility cones adapted for acceleration and turning at angles 30°, 60°

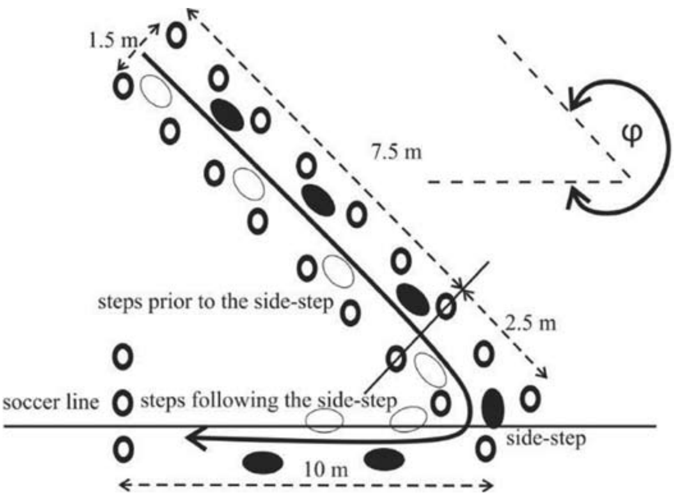

Figure 2: Polygon from agility cones adapted for acceleration straightforward and acceleration while turning at angles from 90° to 180°

Then each player accelerated from all of the approach speeds at maximal effort. Each trial was followed by 1 min rest in order to avoid fatigue. No acceleration exceeded 10 s and we can therefore assume that the effort was based on the disintegration of creatine phosphate (Astrand & Rodahl, 1986). To fully replenish creatine phosphate, 1 min of rest is needed and the soccer players were given this after each measurement. In addition, the players were divided into two groups of four which were measured separately. Every player performed the acceleration and turning at all of the intended approach speeds at two different and random angles. In the meantime, the three other soccer players rested.

Instruments

In order to identify the steps, all trials were recorded with a full high-definition and high speed video-enabled camera Casio EX F1 at a frame rate of 60 Hz (Casio Computer Co., Ltd., Tokyo, Japan). The camera was mounted on a tripod, 1 m in front of the start line and 6 m to the left side of the body. In order to ensure a larger figure in the video footage, the camera operator followed the participants during their trials. A high-end Real Time Kinematics Global Navigation Satellite System (GNSS RTK) with 99.99% position survey reliability, according to the manufacturer (Leica Geosystems AG, Heerbrugg, Switzerland), was used to measure the athletes' trajectories. A rover and a reference station were built using identical hardware components: a dual frequency L1/L2, geodetic, a GNSS RTK receiver Leica GX1230GG, a Leica GLONASS/GPS AX1202 GG survey antenna and Leica Satellite 3AS radio modems for real-time corrections. The system was set to RTK mode and a 20 Hz sampling rate, where it works with SD < 10 mm + 1 ppm (parts per million) and SD < 20 mm + 1 ppm horizontal and vertical accuracy, respectively (Supej, 2010).

During the data collection, the reference station was placed on a fixed tripod located less than 100 m away from all surveyed points in order to transmit real-time corrections and ensure maximum accuracy. To capture the soccer players' trajectories, the rover's receiver, modem and antenna were placed in a small backpack worn by the athlete, with the antenna at the level of the upper thoracic spine (T2-T4). Despite the size (0.212 x 0.166 x 0.079 m) and weight (1.64 kg), the soccer players did not complain about any performance-related discomfort or disturbance.

To control the soccer players' approach speed in real time, two Microgate Polyfemo photocells and Racetime 2 chronometers (Microgate S. r. l., Bolzano, Italy) with an accuracy of 1 ms were mounted 3 m apart from each other at approximately hip height according to the recommendations of Yeadon et al. (Yeadon, Kato, & Kerwin, 1999). The participants were given verbal encouragement to run at a certain chosen approach speed. If the speed deviated by more than ± 2 km/h from the desired speed, the participant was asked to repeat the measurement.

Data analysis

Matlab R2007a (MathWorks, Natick, Massachusetts, USA) was used to analyse the surveyed data. The surveyed trajectories were filtered with the Rauch-Tung-Striebel algorithm (Rauch, Tung, & Striebel, 1965) which uses two unscented Kalman filters running forward and backward in time and performs fixed-interval offline smoothing of the estimated signals. The filters' frequency was set to the lowest value which visually filtered out the steps' fluctuations in speed. The running speed and acceleration at each point of observation were retrieved from the optimal estimation of the Kalman filter. To facilitate a synchronised analysis of video recordings with the GNSS RTK measurements, the video recordings were first transformed to 50 Hz via a frame-to-field method using open-source video-editing software (Virtualdub 1.9.11). Then the lowest squat position was detected on the videos and synchronised with the corresponding GNSS RTK measurement by identifying the change in vertical velocity from downward to upward. Finally, the videos were down-sampled to 20 Hz in order to match the GNSS RTK sampling frequency.

The intervals of foot contacts and corresponding steps were determined on the basis of the video recordings. The approach speed was thereafter determined as the speed before the step in which the lowering of the body's centre of gravity was initiated, while the turning angle in each step was calculated as the difference between the direction of movement at the beginning of the first foot contact and the direction of movement of the start of the following foot contact. The margin for turning in each step of 3.0° was determined from the calculation of the mean value of the maximal absolute mean turning angles during straightforward accelerations from a standstill, while jogging and while running. This value also corresponds to the trunk roll movement during straight path locomotion, which is less than ±3° (Patla et al., 1999). For the starts performed from a standstill, the side-step and the following five steps were examined, while for the flying starts the side-step, the two steps prior to the side-step and the five steps following the side-step were examined.

Statistics

The data were presented as the mean and standard deviation. Correlations between the intended turning angle and the mean magnitude of the actual turning angle in each step and the correlation between the approach speed and the mean magnitude of the actual turning angle in each step were determined using Pearson's coefficient. Thresholds for small, moderate and large correlation coefficients suggested by (Cohen, 1988) were used. A p-value of 0.01 was chosen as the level of statistical significance.

RESULTS

Tables 1, 2 and 3 show the mean change in the direction and corresponding standard deviations of the observed steps when the soccer players accelerated with turning at different approach speeds. For the acceleration and turning from a standstill at angles of 30° and 180° the soccer players needed two steps, at an angle of 60° three steps and at angles of 90°, 120° and 150° four steps to complete the turning. When the soccer players initiated acceleration and turning while already jogging at an angle of 30° the turning lasted from the side-step and two more steps, at an angle of 60° from the side-step and three more steps, at angles of 90° and 120° from the step prior to the side-step and five more steps, at an angle of 150° from the step prior to the side-step and four more steps, and at an angle of 180° from the first to the second step following the side-step. For acceleration and turning while already running at an angle of 30° the turning lasted from the step prior to the side-step and three more steps, at an angle of 60° from the step prior to the side-step and four more steps, at angles of 90° and 120° from the step prior to the side-step and five more steps, at an angle of 150° from the side-step and four more steps, and at an angle of 180° from the side-step to the second step following the side-step.

Table 1: Mean turning angles (°), standard deviations (°) in steps during acceleration and turning from a standstill.

Ita		Side-step	1 sfss	2 sfss	3 sfss	4 sfss	5 sfss
	N	8	8	8	8	8	8
0	Meanta	-4.4*	1.8	0.5	-0.1	0.1	0.0
	SD	3.8	6.0	4.7	1.5	1.4	1.1
30	Meanta	11.9*	23.3*	2.0	0.0	-1.4	-0.5
	SD	8.8	8.7	3.1	1.9	1.4	0.9
60	Meanta	20.2*	36.5*	4.0*	1.5	-1.5	-0.1
	SD	19.2	18.5	5.7	1.4	0.7	0.9
90	Meanta	45.6*	34.6*	6.1*	4.8*	0.8	0.8
	SD	36.5	26.4	9.8	2.5	1.7	1.1
120	Meanta	63.4*	38.8*	7.2*	4.5*	0.9	2.3
	SD	38.4	44.1	9.5	2.2	0.5	1.0
150	Meanta	72.9*	60.8 *	5.1*	5.9*	0.9	2.4
	SD	36.3	41.8	3.1	2.5	2.6	2.0
180	Meanta	93.7*	84.4*	1.2	0.9	0.0	0.1
		51.0	52.5	1.9	2.7	1.6	1.8

Legend: Ita – intended turning angle (°), sfss – step following side-step, meanta – mean turning angle, SD – standard deviation, * - turning angle greater than 3.0°.

Table 2: Mean turning angles (°) and standard deviations (°) in steps during acceleration and turning while already jogging.

Ita	Mappsp		2 spss	1 spss	Side-step	1 sfss	2 sfss	3 sfss	4 sfss	5 sfss
		N	8	8	8	8	8	8	8	8
0	10.1±1.7	Meanta	1.8	2.7	0.2	-0.1	-0.2	-0.3	0.0	-0.3
		SD	4.5	4.7	1.4	1.0	0.8	0.7	0.8	0.7
30	10.1±1.4	Meanta	-2.5	2.5	7.5*	13.0*	3.2*	1.6	-0.6	0.6
		SD	4.2	3.2	6.7	14.8	5.2	1.7	1.6	1.5
60	9.6±1.1	Meanta	-2.3	1.6	10.7*	26.6*	12.7*	6.2*	2.1	0.8
		SD	2.7	3.2	2.7	8.0	5.9	2.3	2.2	1.2
90	9.5±1.3	Meanta	0.1	5.0*	15.0*	36.2*	20.7*	7.8*	3.5*	2.4
		SD	4.5	7.0	7.3	17.1	8.8	2.2	2.9	1.5
120	10.1±1.6	Meanta	-0.1	4.0*	16.2*	36.7*	51.7*	8.0*	3.0*	1.5
		SD	1.8	4.9	19.7	13.3	22.7	4.0	1.5	1.9
150	9.9±1.3	Meanta	1.9	5.7*	9.6*	60.8*	63.6*	5.2*	0.5	0.9
		SD	2.7	3.7	1.7	36.2	37.4	5.0	2.9	1.1
180	10.8±0.8	Meanta	1.2	0.5	1.5	115.3*	57.9*	2.5	1.4	-0.6
		SD	0.7	4.8	2.9	75.9	75.0	1.0	0.9	1.7

Legend: Ita – intended turning angle (°), Mappsp – approach speed (km/h), spss – step prior to side-step, sfss – step following side-step, meanta – mean turning angle, SD – standard deviation, * - turning angle greater than 3.0°.

Table 3: Mean turning angles (°) and standard deviations (°) in steps during acceleration and turning while already running.

Ita	Mappsp		2 spss	1 spss	Side-step	1 sfss	2 sfss	3 sfss	4 sfss	5 sfss
		N	8	8	8	8	8	8	8	8
0	15.6±1.0	Meanta	-1.2	0.2	-0.1	0.0	-0.5	0.0	-0.1	0.2
		SD	4.3	1.5	1.5	0.8	0.9	0.8	0.5	0.5
30	15.1±0.8	Meanta	-1.2	3.3*	6.9*	11.9*	6.9*	2.6	0.3	0.2
		SD	4.3	1.7	1.3	2.4	2.6	0.8	0.6	0.7
60	14.9±1.2	Meanta	1.4	5.0*	12.7*	16.6*	13.1*	5.8*	1.9	0.8
		SD	1.9	2.9	2.3	4.1	4.8	1.5	1.5	2.8
90	15.0±0.7	Meanta	0.9	8.9*	14.6*	24.6*	24.9*	13.5*	3.3*	1.3
		SD	0.6	11.4	18.7	6.7	16.9	4.3	4.2	2.5
120	14.6±1.5	Meanta	1.2	3.3*	7.0*	38.2*	52.2*	10.8*	3.6*	2.0
		SD	2.1	3.8	5.0	14.4	12.1	4.7	3.1	1.3
150	14.7±1.7	Meanta	2.8	2.8	8.3*	67.9*	62.8*	3.3*	0.1	0.6
		SD	1.2	2.4	13.6	66.2	72.7	3.5	2.1	1.2
180	15.6±1.4	Meanta	1.2	2.4	3.2*	133.5*	40.3*	1.3	-1.2	0.4
		SD	1.2	1.1	0.9	81.4	82.5	2.3	1.0	0.4

Legend: Ita – intended turning angle (°), Mappsp – mean approach speed (km/h), spss – step prior to side-step, sfss – step following side-step, meanta – mean turning angle, SD – standard deviation, * - turning angle greater than 3.0°.

Table 4 shows the correlation between the intended turning angle and the actual average turning angle in the observed steps while accelerating straightforward and while accelerating with a turn at different approach speeds. With starts made while already running, the intended turning angle had a strong correlation with the average turning angle two steps prior to the side-step, with starts from a standstill the intended turning angle had a strong correlation with the average turning angle during the side-step and the first step following the side-step, whereas with starts while already jogging and running the intended turning angle had a strong correlation with the average turning angle during the first step following the side-step and during the second step following the side-step.

Table 4: Correlation between the intended turning angle and the actual average turning angle in observed steps during acceleration straightforward and acceleration with turning at different approach speeds.

		2 spss	1 spss	Side-step	1 sfss	2 sfss	3 sfss	4 sfss	5 sfss
	N	7	7	7	7	7	7	7	7
Standstill	Pearson Correlation			.995*	.950*	.345	.553	.493	.556
	Sig. (2-tailed)			.000	.001	.449	.198	.261	.195
Jogging	Pearson Correlation	.384	.106	.170	.919*	.952*	.420	.362	.051
	Sig. (2-tailed)	.396	.822	.716	.003	.001	.348	.425	.913
Running	Pearson Correlation	.805*	.115	.103	.897*	.881*	.155	-.086	.308
	Sig. (2-tailed)	.029	.805	.826	.006	.009	.740	.855	.501

Legend: Spss – step prior to side-step, sfss – step following side-step, Sig. – significance, * - $p < 0.01$.

Table 5: Correlation between the approach speed and turning angle in observed steps during acceleration straightforward and acceleration with turning.

		2 spss	1 spss	Side-step	1 sfss	2 sfss	3 sfss	4 sfss	5 sfss
Ita	N	16	16	24	24	24	24	24	24
0°	Pearson Correlation	-.456	-.518	.626*	-.234	-.153	.021	-.112	.088
	Sig. (2-tailed)	.076	.040	.001	.272	.474	.923	.603	.681
30°	Pearson Correlation	.248	-.009	-.330	-.436	.473	.620*	.521*	.349
	Sig. (2-tailed)	.354	.972	.115	.033	.019	.001	.009	.095
60°	Pearson Correlation	.707*	.444	-.327	-.564*	.585*	.713*	.679*	.249
	Sig. (2-tailed)	.002	.085	.119	.004	.003	.000	.000	.240
90°	Pearson Correlation	.043	.199	-.538*	-.158	.600*	.752*	.360	.117
	Sig. (2-tailed)	.873	.461	.007	.461	.002	.000	.084	.585
120°	Pearson Correlation	.512	-.166	-.777*	.076	.772*	.582*	.518*	-.051
	Sig. (2-tailed)	.043	.540	.000	.724	.000	.003	.010	.812
150°	Pearson Correlation	.221	-.259	-.787*	.203	.371	-.272	-.251	-.438
	Sig. (2-tailed)	.410	.332	.000	.342	.074	.199	.238	.032
180°	Pearson Correlation	.342	.147	-.777*	.316	.254	.148	-.151	.069
	Sig. (2-tailed)	.194	.587	.000	.132	.232	.491	.481	.748

Legend: Ita – Intended turning angle (°), spss – step prior to side-step, sfss – step following side-step, Sig. – significance, * - $p < 0.01$.

Table 5 shows the correlation between the approach speed and the turning angle in the observed steps while accelerating straightforward and accelerating while turning. There was a moderate positive correlation between the approach speed and acceleration with a turn at an angle of 60° two steps prior to the side-step. There was also a moderate positive correlation between the approach speed and acceleration straightforward and a moderate negative correlation between the approach speed and acceleration while turning at angles of 90° to 180° while performing the side-step. A moderate negative correlation between the approach speed and acceleration while turning was also found during the first step following the side-step when the soccer players accelerated with a turn at an angle of 60°. When the soccer players accelerated while turning in different directions the approach speed had a moderate positive correlation in the second step following the side-step while turning at angles of 60° to 120°, in the third step following the side-step while turning at angles of 30° to 120°, and in the fourth step following the side-step while turning at angles of 30°, 60° and 120°.

DISCUSSION AND CONCLUSIONS

The main findings of the study are that: acceleration while turning from a standstill could last until the second or third step had been performed following the side-step depending on the angle of turning, whereas at a higher approach speed the turning could already be seen while performing the step prior to the side-step, the side-step or the step following the side-step and could last until the second, third or even fourth step had been performed following the side-step, depending on the angle of turning. The intended turning angle revealed a large effect on the magnitude of the turning angle during the side-step and the following step for acceleration and turning from a standstill, and during the first two steps following the side-step for starts made while already jogging and running. Further, a major part of the turning began earlier at a lower approach speed, allowing for the quicker completion of the turn.

With acceleration while turning, the step performed two steps prior to the side-step was studied when the participants entered at the approach speeds (Tables 2 & 3). The high correlation between the intended turning angle and the actual average turning angle for starts while running suggest preparations for a change in direction with starts at higher approach speeds, although for all approach speeds the value of the turning angle for this step remains below 3^0 (the chosen threshold that determined the presence of turning).

In the step prior to the side-step, the results demonstrated a relatively low rate of turning when the soccer players accelerated while turning at intended angles from 90° to 150° while jogging, and with an intended turning angle from 30° to 120° while running with the highest rate of turning at 90° (Tables 2 & 3). This is in line with previous studies showing that athletes typically display a lateral movement directed towards the intended running line prior to the side-step when the movement direction is planned in advance (Andrews, McLeod, Ward, & Howard, 1977; Wheeler & Sayers, 2010). The main exceptions are the 150° and 180° cases where the absence of turning was noticed.

The proficient generation of lateral movement speed during the side-step is a critical component of evasive agility skill execution in multi-lateral sports (Wheeler & Sayers, 2010). The analysis of the side-step showed that during acceleration and turning at all approach speeds the rate of turning exceeded the selected threshold with the exception of acceleration when turning at an angle of 180° while already jogging (Table 2). When performing the side-step, the greatest changes in direction occurred during acceleration with turning from a standstill when the bigger desired change in direction results in a greater actual change in direction (Table 1). This indicates that the side-step is one of two key steps for acceleration and turning from a standstill. Moreover, the higher approach speed reduced the actual turning angle during acceleration while turning at angles of ≥ 90°, but for a lower turning angle of 60° the same effect occurred in the step following the side-step (Table 5). These results are likely to be connected with findings showing that to change direction at higher speeds athletes must first decelerate and lower their centre of gravity (Sayers, 2000).

In the step that followed the side-step the turning angle during acceleration and turning always exceeded the limit raised for the turning and the turning angle in this step was positively influenced by the intended turning angle regardless of the approach speed of movement (Table 4). According to the high correlation between the intended turning angle and the actual turning angle while performing the step that followed the side-step, this step tends to be one of two main steps irrespective of the approach speed.

For starts from a standstill, the second step following the side-step proved to be the step for making minor corrections in the turning angle during acceleration while turning (Table 1). For the transition from jogging and turning at an angle of 60° to jogging straightforward, two major steps – side-step, and the following step – were required, which is in line with previous findings (Jindrich & Mu, 2009). However, during accelerating and turning for starts while already jogging and running, the second step following the side-step also tended to be one of two major ones due to the high correlation between the intended turning angle and the actual turning angle while performing the step after the side-step (Tables 2, 3). The actual turning angle in this second step following the side-step was positively influenced by the intended turning angle when the soccer players had a flying start (Table 4). A higher approach speed increased the actual turning angle during acceleration and turning at angles of 60° to 120° (Table 5), which can be explained as a form of compensation for the relatively low rates of turning during the side-steps in these trials.

Compensatory adjustments may also occur in the third and/or fourth step following the side-step, depending on the intended turning angle. This is similar to findings showing that acceleration while turning sometimes requires several steps before completion (Ohtsuki, Yanese, & Aoki, 1987). While performing the third step following the side-step, minor corrections in turning angles occurred when the soccer players accelerated while turning from a standstill at intended turning angles of between 90° and 150° and when the soccer players accelerated while turning when already jogging or running at angles of ≥ 60°. A higher approach speed increased the actual turning angle in this 3rd step during acceleration and turning for intended turning angles of ≤ 120°. A minor correction in turning during the fourth step following the side-step occurred when accelerating while turning from a flying start for intended angles of between 90° and 120°. Since the 4th step after the side-step seems to be quite late for turning, in the future it would be beneficial to investigate whether proper training can improve the performance by finishing the turning a step earlier.

All of the present findings are limited by the estimation of the centre of mass movement derived by a high-end GNSS system where it was not possible to place the surveying antenna exactly in the centre of the body's mass. Another limitation is the relatively low frequency of the data collection which however, in relation to the duration and displacements of the steps, was sufficient for the purpose of the study. All measurements were carried out with soccer players without a ball, which affected the results accordingly. However, soccer players are only in possession of the ball during 1.2 – 2.4% of the total distance covered (Di Salvo et al., 2007). The results therefore reflect most of the acceleration and turning undertaken during a game.

Our study's main advantage over others is that it includes a set of approach speeds from which it makes sense to accelerate and a set of several angles across the range in which a soccer player moves during a game. In addition, all of the trials were performed on a soccer field using full soccer player equipment. In the future, we intend to investigate the influence of a ball on soccer players' ability to turn and compare those results with the present results where no ball was involved. It would be beneficial to investigate whether the results would remain comparable when fatigue appears during a game. Another plan is to perform measurements of whole body 3D kinematics to allow the observation of changes in technique and possible connections with injuries.

In conclusion, our study enables us to better understand the initiation, development and completion of acceleration while turning at different approach speeds, which is a determinant of field sports performance (Sheppard & Young, 2006). Acceleration with a turn is mainly performed in two major steps, the side-step and the following step for starts from a standstill, and the first two steps following the side-step from a jogging or running start in which the magnitude of the turning angle depends on the soccer player's intentions to accelerate in a certain direction. The effectiveness of how these major steps are executed is probably one of the key moments in a one-on-one game situation. With starts while already jogging or running there could be two or fewer preparatory steps prior to the two major steps depending on the intended turning angle and there could be at least one or more corrective steps following the two major steps depending on the intended turning angle. Finally, the present study could be used as a basis for understanding and modelling soccer players' acceleration while turning at different approach speeds. The findings could also be used in other sports even though not all of them are played on a natural playing ground, i.e. grass, using studs.

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