©Journal of Sports Science and Medicine (2014) **13,** 423-429
http://www.jssm.org

Research article

What is the Safest Sprint Starting Position for American Football Players?

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Abstract

The main objective of this study was to perform a biomechanical analysis of three different sprint start patterns to determine the safest position in term of neck injury and Sport-Related Concussion (SRC). The second objective was to collect data on the learning process effect between football players and non-players. Three different sprint initial positions adopted by football players were studied (i.e., 4-, 3- and 2-point positions). Twenty five young healthy males, including 12 football players, participated to this study. A stereophotogrammetric system (i.e., Vicon) was used to record motion patterns and body segments positions. Various measurements related to head and trunk orientation, and player field-of-view were obtained (e.g., head height, trunk bending, time to reach upright position, head speed (vertical direction) and body speed (horizontal direction)). Learning process was found to have no influence on studied parameters. Head redress is also delayed when adopting a 4-point position leading to a reduce field-of-view during the start and increasing therefore the probability of collision. Concerning the three different positions, the 4-point position seems to be the more dangerous because leading to higher kinetic energy than the 2- and 3-point start positions. This study proposes a first biomechanical approach to understand risk/benefit balance for athletes for those three different start positions. Results suggested that the 4-point position is the most risky for football players.

Key words: Sports, sports medicine, brain concussion, biomechanics.

Introduction

Safety in sports, especially in contact sports is an important issue. Concussions are among the most critical neurological injuries that can occur during football (or "American football" as it is called some regions of the world). Sport-related concussions (SRC) may occur alone or in combination with cervical spine (Bhamra et al., 2012; Cantu et al., 2013; Rihn et al., 2009) and/or brachial plexus injuries (Altaf et al., 2012; Cantu et al., 2013; Lee et al., 2011). In the United States of America (USA) approximately 300,000 SRC are listed every year (Marar et al., 2012). Football is the most affected sport (47% of the SRC are met in football). The overall concussion rate is 2.5 per 10,000 athletes and 6.4/10,000 in football (Marar et al., 2012). Child and adolescent reported SRC in the USA has also increased of 60% during the last decade (Gessel et al. 2007). Other severe neurological complications can occur separate from or in conjunction with concussion, such as subarachnoid hemorrhage, epidural or subdural hematomas, cerebral edema (Zuckerman et al., 2012), and could also induce neuropsychological and cognitive changes years after trauma occurred (De Beaumont et al., 2009). It has been shown that retired players present Alzheimer syndrome more precocious than a control group (Guskiewicz et al., 2005) (note, however that the prevalence was not statistically higher). Repeated mild traumatic brain injuries are major factors contributing to Parkinson disease (Lee et al., 2012). Second-impact syndrome may occur while the athlete is still symptomatic and healing from a previous concussion; such new impact can worsen the primary SRC condition (Weinstein et al., 2013). Guidelines for evaluation and management of SRC have been established (Harmon et al., 2013). Different "return-to-play" protocols are under current discussion to avoid second-impact factor (Doolan et al., 2012, Mayers et al., 2012) and allow athlete to perform sport in safety (http://www.abc.net.au/4corners/documents/concussion2012/IRB_Concussion_Guidelines_2011.pdf.). Increasing safety in football is therefore an important question in the USA. Indeed not only the National Football League (NFL) is requesting to increase players' safety (http://www.nfl.com/news/story/0ap1000000058439/article/roger-goodell-on-player-safety-we-all-have-to-do-more) but also the USA highest authorities previously worried about players' safety (http://www.cbssports.com/nfl/blog/nfl-rapidreports/21619423/president-obama-for-players-sake-reduce-violence-of-football). One issue which could lead to injuries is the initial sprint position, e.g. the so-called 'starting position in 3 points'. However, no previous study has tried to evaluate the influence of this initial position on the risk of dangerous collision.

Although motion analysis is frequently used in daily clinics, only few biomechanical studies aim to prevent sport injuries. A previous study reported a percent asymmetry for runner in order to detect injury risk when running (Rumpf et al., 2014). Another study assessed visual and sensory performance of football players trying to identify at-risk athlete (Harpham et al., 2014). This seems to show that there is an increasing awareness in the field, and that a trend is set to identify specific parameters to estimate at-risk players. This study is similar in nature and focused on analyzing three different sprint start positions by comparing their respective biomechanical parameters related to neck injury, concussion risk and head collision of players after a so-called "pre-snap" (i.e., position of the teams facing each other in one offensive versus a defensive line). Influence of learning process between players and non-players was also addressed.

Methods

Subjects

Received: 26 November 2013 / Accepted: 05 February 2014 / Published (online): 01 May 2014

Twenty five young healthy males participated in this study (height = 1.81 ± 0.09 m, weight = 80 ± 16 kg, age = 24 ± 2 years old). Twelve of them were football players (height = 1.81 ± 0.08 m, weight = 89 ± 15 kg, age = 24 ± 3 years old, mean experience in football = 5 years, 4 hours of practice per week plus one match). A population of thirteen non-player participants was selected as control group. The control group selection occurred in order to match the height player group (height = 1.80 ± 0.09 m, weight = 73 ± 13 kg, age = 23 ± 3 years old). All participants in the non-player group were students from the ULB Faculty of Motor Sciences and well-trained in athletics (all sport amateur with regular sport training during their university program: 8 to 10 hours of sport/week including athletic, swimming, gymnastic, ball sports, etc.).This study was approved by the Ethical Committee of the Erasme Hospital (B406201112048) and written informed consent was obtained from all participants prior to participation in the study.

Methodology

A stereophotogrammetric system (Vicon, 8 MXT40s cameras, Vicon Nexus software, frequency: 100Hz) was used to record motions and positions parameters. 12 reflective markers (4 on the head, 4 on the thorax, 4 on the pelvis) were placed on the skin following the Plug-In-Gait model (Figure 1). Participants were in underwear and barefoot to perform the different study trials. All measurements occurred inside the authors' movement laboratory on a synthetic floor.

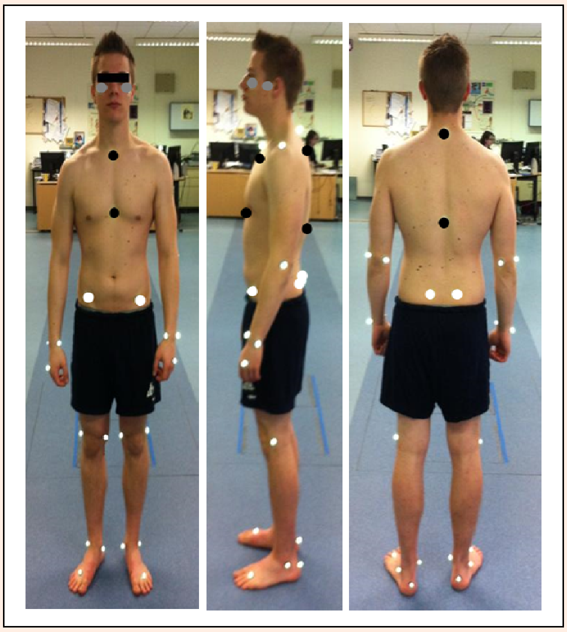

Figure 1. **Markers' placement. 4 markers on the head (grey color), 4 markers on the thorax (black color) and 4 markers on the pelvis (white color).**

Participants were asked to perform 3 sprints starting from 3 different initial positions that are found in football practice. These three positions (called 2-point, 3-point and 4-point starts) are schematized in Figure 2. Prior to motion capture, an experienced football player first demonstrated the different initial positions to adopt. Participants were then invited to perform the motion once as non-recorded warm-up test. Then three successive trials were recorded for each modality. A total of 9 datasets were collected for each participant (3 start positions times 3 trials).

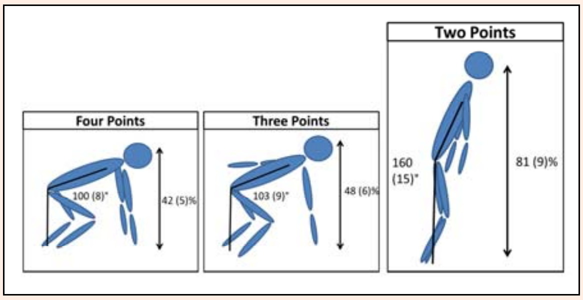

Figure 2. **Initial position for the three initial start positions with the angle of the trunk and the head's height (in percentage).**

Body segments position and global motion were statistically analyzed for each participant as following. The instantaneous head height was expressed in percent of the maximum head height (i.e., measured when subject was in standing position). Two angles were calculated: inclination of the trunk relative to the floor (Trunk inclination, in degrees), and the angle between head and trunk (Trunk head, in degrees). These two angles were further computed into a so-called *"Verticality"* angle (in degrees) obtained from Eq. 1:

$$\text{Verticality} = (180-\text{ Trunk inclination})+(180-\text{Trunk head}) \qquad \text{Eq. 1}$$

Verticality of the head is reached when this angle is close to 0°. It was assumed that the width of the participant visual field-of-view is optimal when Verticality is close to 0°.

The height of the head was also assumed to be directly related to visual field and head injury risk minimization: the higher the head, the larger the visual field and the lower the injury risk. A ratio between the height of the head and *Verticality* was computed as *"Field-of-View"* (FOV) (Eq. 2):

$$\text{FOV} = \text{Height of the head (\%)} / \text{Verticality (°)} \qquad \text{Eq. 2}$$

For each trial data obtained from each participant, the start and the end of the motion where manually detected by the same observer from the range-of-motion (ROM) of the head height expressed over the time and from head's acceleration. Start of the analyzed motion was set when head acceleration started increasing. The end of the same motion was set when the instantaneous head height reached the position of the head in standing position. For each participant, the 3 repetitions related to the same start position were averaged. The so-called *redress* time was obtained by subtracting the end-time from the trial start time. The vertical head speed and acceleration were computed from the head height and the redress time. The body speed was computed 1 second after the start of the motion.

Table 2. Mean (sd) values obtain for the three different sprint start, initial position and values during the motion for football players and non-players and mean values of both groups (bottom line).

		4 Points		3 Points		2 Points	
		US Football player	Non player	US Football player	Non player	US Football player	Non player
Initial Position	Head height (%)	**39 (4)**	**44 (4)***	46 (5)	50 (7)	81 (8)	80 (10)
		42 (5)		**48 (6) †**		**81 (9) § ‡**	
	Trunk inclination (°)	103 (11)	98 (4)	**106 (5)**	**100 (10)***	160 (13)	159 (16)
		100 (8)		103 (9)		**160 (15) § ‡**	
	Trunk head (°)	135 (26)	137 (15)	140 (16)	144 (14)	145 (6)	143 (11)
		136 (20)		**142 (15) †**		144 (9)	
	Verticality (°)	122 (23)	125 (13)	114 (17)	117 (17)	55 (19)	58 (24)
		123 (18)		**115 (17) †**		**55 (21) § ‡**	
	FOV	.34 (.05)	.36 (.04)	.41 (.07)	.43 (.07)	1.58 (.40)	1.54 (.46)
		.35 (.04)		**.42 (.07) †**		**1.56 (0.43) § ‡**	
Motion	Redress Time (s)	1.25 (.20)	1.18 (.20)	1.23 (.20)	1.18 (.10)	1.30 (.20)	1.33 (.20)
		1.22 (.18)		1.22 (0.18)		1.32 (0.22)	
	Head Speed (m·s^{-1})	.90 (.13)	.85 (.08)	.80 (.15)	.77 (.11)	.27 (.14)	.27 (.15)
		.87 (.11)		**.78 (.13) †**		**.27 (.14) § ‡**	
	Body Speed (m·s^{-1})	2.70 (.37)	2.63 (.69)	2.59 (.59)	2.63 (.58)	2.21 (.47)	2.44 (.56)
		2.67 (.55)		2.61 (0.56)		**2.33 (.52) § ‡**	

* indicates difference between US football player and non-player (at 0.05 level). † indicates difference between 4 and 3 points (at 0.05 level). ‡ indicates difference between 4 and 2 points (at 0.05 level). § indicates difference between 3 and 2 points (at 0.05 level)

The averaged motion where then time normalized in order to compare curves for Verticality, FOV, Head Angle, Head Speed, Head Acceleration and Body Speed. Coefficients of Multiple Correlations (CMC) were applied to compare trajectories of head and trunk during the three different motions.

To assess the severity of potential impacts between the head of two players facing each other and adopting various start positions, the kinetic energy of such impacts was estimated using Eq. 3. Results are presented in Table 1.

$$Kinetic\ energy = \frac{m * V^2}{2} \qquad \text{Eq. 3}$$

m =7.2kg (0.081*mean weight) (Winter 2009)

$$V = \sqrt{Body\ Speed^2 + Head\ Speed^2}$$

Table 1. Estimation of Kinetic Energy for 6 different potential collisions related to the three different start position adopted by two players facing each other.

Players 1 start	Players 2 start	Collision energy (in J)	% increase
2-point	2-point	79.3	0 % (ref value)
2-point	3 Points	92.6	17%
2-point	4 Points	95.7	21%
3 Points	3 Points	106.9	35%
3 Points	4 Points	110.3	39%
4 Points	4 Points	113.7	43%

ref value: reference value

Statistical analysis

Statistical analysis was performed using SPSS 18. Kolmogorov-Smirnov tests were used to assess normality of the data. Parametric tests were used because all data were normally distributed. ANOVA tests were applied to compare start modalities and the differences between trained and untrained groups. As differences were found with ANOVA, post-hoc tests (i.e., Bonferroni tests) were then applied to determine groups showing differences between each other's. Coefficients of multiple correlations (CMC) were computed to compare head and trunk's trajectories during the early phases of the sprint.

Results

Table 2 summarizes the mean results for the three different positions and the two groups. Figure 2 summarizes starting position for the three sprint starts, Figure 3 the evolution of head's height during the early phase of the sprint. Adopting a 4-point start position leads to a lowering of the FOV (by 0.07) compared to 3-points start position (Table 2). The FOV is increased when adopting a 2-points starting position because the trunk is more vertical. Except for the initial head height during 4-point start (5%) no difference was found between football players and non-players for initial position.

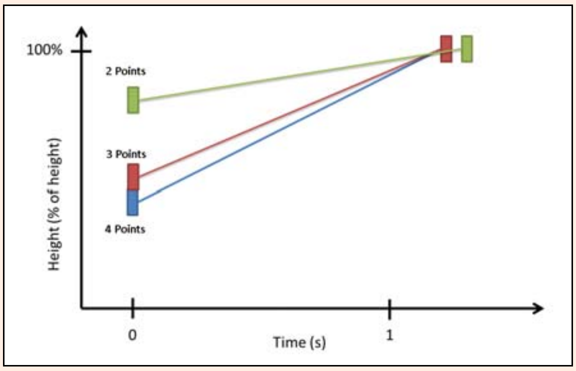

Figure 3. Evolution of head's height during early phase of the sprint.

Concerning the motion no difference was found for the redress time: the Head Speed (in the vertical direction) is higher for the 4-point start position compared to the 3-points (difference of 0.11 m·s^{-1}, see Table 2) and 2-point (difference of 0.60 m·s^{-1}) because initial position of the head is lower in 4-points start. For the Body Speed

Table 3. Comparison of the three different sprint positions. CMC are computed during the first second for football players and non players and mean values of both groups (bottom line).

	4 Points Vs 3 Points		4 Points Vs 2 Points		3 Points Vs 2 Points	
	US Football player	Non player	US Football player	Non player	US Football player	Non player
Verticality	.90 (.13)	.87 (.24)	.66 (.14)	.74 (.19)	.78 (.13)	.70 (.25)
	.89 (.19)		.71 (.17)		.71 (.17)	
FOV	.91 (.11)	.70 (.13)	.70 (.13)	.79 (.11)	.79 (.11)	.71 (.20)
	.90 (.16)		.71 (.15)		0.71 (.15)	
Head Angle	.67 (.27)	.69 (.65)	.69 (.65)	.71 (.17)	.71 (.17)	.69 (.24)
	.64 (.24)		.67 (.23)		.67 (.23)	
Head Speed	.71 (.17)	.61 (.21)	.61 (.21)	.61 (.21)	.61 (.21)	.68 (.21)
	.72 (.16)		.65 (.21)		.65 (.21)	
Head Acceleration	.69 (.15)	.59 (.19)	.59 (.19)	.67 (.21)	.67 (.21)	.65 (.18)
	.68 (.18)		.64 (.18)		.64 (.18)	

No statistical difference was found between players and non-players.

(horizontal displacement) no difference was found between the 3- and 4-points but speed was lower for the 2-point start (about 0.30 m·s^{-1} of difference, see Table 2). No difference was found between players and non-players during the early phase of the sprint.

Concerning the comparison for group of players and non-players results of the three start position for trunk's verticality, the FOV and head displacements (angle, speed and acceleration) did not differ statistically (Table 3). Concerning verticality angle and FOV between position best correlations were found between 3 and 4 points (0.89 and 0.90 respectively) (Table 3). Concerning head parameters (angle, speed and acceleration) it is interesting to note that results are very similar for those three positions: CMC = 0.64, 0.67 and 0.70 for 4-point vs. 3-point, 4-point vs. 2-point, and 3-point vs. 2-point, respectively for the Head Angle. Full results are presented in Table 3. Figure 4 presented head displacement, speed and acceleration for the three start position for these two groups.

Discussion

The field-of-view (FOV)

To avoid head collision, thus potential risk of concussion and/or cervical spine injuries, athletes must be aware of the position of the other surrounding players. It is natural to diminish head's height to protect eyes and faces (Heck, 1998) Coach and trainer's advises include visual tracking of potential obstacles to avoid collision or at least anticipate impact. Visual and sensory performance may influence an individual's ability to interpret environmental clues, to anticipate opponents' actions, and to create appropriate motor responses limiting the severity of an impending head impact (Harpham et al., 2014). By lowering their head, athletes are less prepared to absorb the shock. Shock energy will be absorbed on the head, and not on the trunk and shoulder; note that it has been previously shown that that initiate contact with shoulder while keeping the head as high as possible is the safest position (Torg et al., 1993). Therefore the largest the FOV the lowest the injury risk. Optimal FOV is of importance for assessing player's safety. In this paper, head height and angle between head and trunk were processed to assess FOV and the risk of cervical spine injuries indirectly. Spearing is a frequent cause of cervical injuries. It occurs when the players use their head as the initial point of contact making contact at the top of the helmet (Brigham and Warren, 2003; Torg et al., 1993). Table 3 presents results of CMC for position comparison. The comparison of the two lower positions (4- and 3-point positions) shows similar patterns for verticality of the trunk (CMC = 0.89) despite some differences in head angle (CMC = 0.64). Regarding the comparison of the 3- and 4-point positions with the 2-point (2 points) CMC values are smaller due to important differences in the starting position. In order to reduce the injury risk it is better to initiate the contact with shoulder keeping the head as high as possible (Cantu and Mueller, 2003) to avoid spearing effect on cervical spine (Brigham and Warren, 2003; Torg et al., 1993). The concept of FOV was adopted in this study as a new variable taking into account the variation of both head height and the angle between head and trunk. As for verticality similar results were found for CMC. In the initial position the FOV is more than 4 times lower in 4-point compared to 2-point position. More surprisingly no significant difference was found for the redress time between the three positions. Therefore head's speed (in the vertical direction) is higher for the lower position. Secondly the body speed (displacement in the horizontal direction) was found to be more important for the two lower start positions then for the 2-point one (15% and 12% higher for the 4-point and 3-point positions, respectively).

The kinetic energy

In case of collision the energy is thus more important for these positions. It has been assumed that head collision would occur approximately one second after two players facing each other started. The kinetic energy of a collision between players starting from the different positions was estimated (Table 1). A kinetic energy difference of about 43% was observed between a collision occurring between 2 players adopting a 2-point start and a collision between 2 players adopting a 4-point start. The highest kinetic energy was found during a collision between two players adopting a 4-point start (113.7 J). One previous study has analyzed some biomechanical variables during head impact using accelerometers placed inside the helmet (Brioglio et al., 2009). Measuring acceleration and deceleration directly during real impact the authors estimated a mean impact force of 1300 N (Broglio et al., 2009). Although the impact location of the head is an important

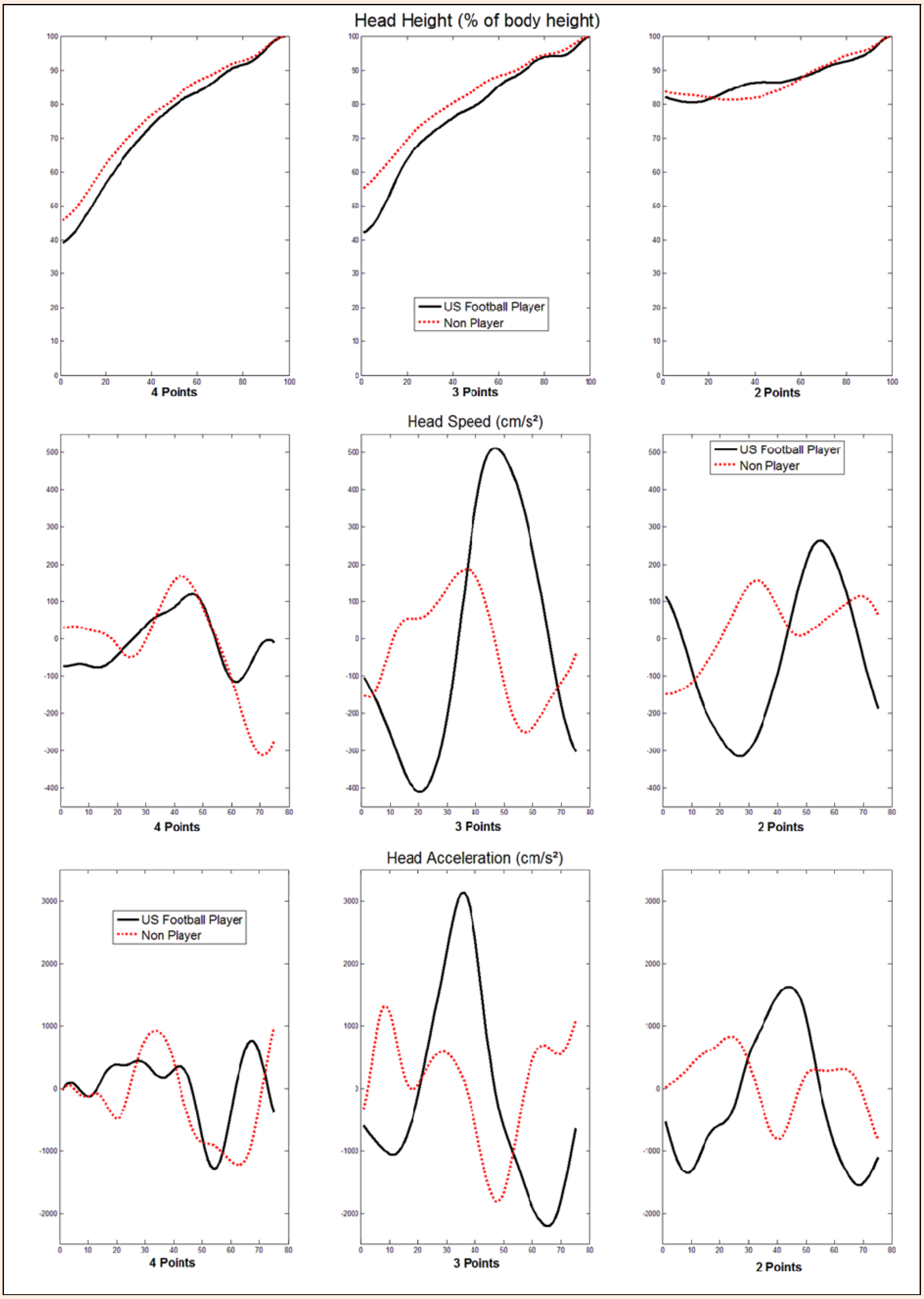

Figure 4. **Evolution of head's height during the motion. Comparison between football players and non-Players. Times are normalized.**

factor to understand SRC risks and the severity of potential injuries (Broglio et al., 2009; Greenwald et al., 2008), it has been shown that current biomechanical analysis based on accelerometers are not directly related with post-concussion outcomes (Broglio et al., 2011). Our study seems to indicate that there is a link between player start position, player FOV and collision energy: the start position generating the highest level of energy is unfortunately also the position leading to the smallest FOV; SRC risk is therefore increased.

The learning effect

Two statistically significant differences were found comparing player versus non-player. These differences were related to the 3- and 4-point start positions. Players' head are lower and trunk more bended compared to non-players. Despite these start difference, no statistical differences were found during the motion for studied parameters (redress time, head and body speeds). As shown in the Table 3 and Figure 4 the trajectories of the head are similar in both groups.

This lack of performance difference can be explained by the fact the group of non-players was recruited within the Faculty of Motor Sciences and has thus an important sport background (e.g., no difference was found concerning the body speed between these two populations). The results seem therefore to indicate that the player group show a trend related to a more bended position leading to a reduced FOV.

Limitations of the study

One must keep in mind that measurements were performed within a gait laboratory; participants were in underwear, barefoot on a synthetic floor (more rigid and sliding that a real football field)and without opponent facing the player. Conditions were thus different from a sprint realized outside on a football field (artificial or natural turf) wearing all equipment. One can therefore assume that results would be different in equipment but these differences would be the same for the three start positions because of systematic differences. The main focus of this work was to compare three different start positions; the influence of these systematic differences is thus, in the author's opinion, limited.

Conclusion

Two main results can be underlined from this study. At first, the head location is lower and the redress speed higher when the player is adopting a 4-point start pattern. Compared to a 3-point start position, adopting a 4-point start position increases by 8% the kinetic energy in case of collision with an opponent adopting the same start position. The 2-point start increased FOV thanks to a more vertical and higher head orientation and location. This specific position should therefore increases players' safety; however it also leads to lower body speed that could potentially reduce player performance. Secondly, specific football training seems to have no influence on starting performance and by the way on the "risky position" compared to a control group of well-trained people. Nevertheless this lack of difference could be due to the sport background of the control population. The authors acknowledge that the studied populations did not include professional football players (the study has been performed in Belgium where no such professionals are to be found) and that the reported numbers (e.g., for speed and energy) are probably underestimated compared to the same measurements that would be performed on professional players. Nevertheless, it is expected that the overall conclusions of this study is valid for all player categories. In conclusion, security of the player should be increased with equipment. It has been however previously demonstrated that helmet wearing did not prevent or significantly reduce concussion incidence (Daneshar et al. 2011; Navorro, 2011). Another option to increase safety is a modification of the game rules. This study has attempted to evaluate risk/benefice balance of three different positions pattern on run start. In addition to classical impact data analyses, we have tried to measure the influence of initial position on risk/benefit balance of injuries. By reducing kinetic energy in case of collision and improving player FOV, Results show that the 2-point start seems safer than the largely adopted 3-point start. Speed however decreases. It is now up to the players, clubs and federations to set priorities between player safety and speed. Nevertheless, the 2-point start position is advised to players who are recovering from a previous concussion. Adopting a 2-point start position during recovery period should allow players to reintegrate training programs quicker and safer by increasing the player's field-of-view and by decreasing the probability of a second-impact syndrome.

Acknowledgment

The authors thank the players of the Brussels Black Angels and the students of the Faculty of Motor Sciences.

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Key points

- Motion analysis and biomechanical analysis of the initial start position of the sprint could be used to increase the safety of the football players.
- Analysis of kinematic and trajectory of the head and the time to reach the upright position could be used to determine whether or not a player can return to play after concussion.
- A balance needs to be found between player's safety (2-point start) and speed (4-point start).

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