Human Movement Science 29 (2010) 412–425

Contents lists available at ScienceDirect

Human Movement Science

journal homepage: www.elsevier.com/locate/humov

Balancing deceit and disguise: How to successfully fool the defender in a 1 vs. 1 situation in rugby

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ARTICLE INFO

Article history:
Available online 24 April 2010

PsycINFO classification:
2300
2330
3720

Keywords:
Deception
Biomechanics
Kinematics
Sport

ABSTRACT

Suddenly changing direction requires a whole body reorientation strategy. In sporting duels such as an attacker vs. a defender in rugby, successful body orientation/reorientation strategies are essential for successful performance. The aim of this study is to examine which biomechanical factors, while taking into account biomechanical constraints, are used by an attacker in a 1 vs. 1 duel in rugby. More specifically we wanted to examine how an attacker tries to deceive the defender yet disguise his intentions by comparing effective deceptive movements (DM^+), ineffective deceptive movements (DM^-), and non-deceptive movements (NDM). Eight French amateur expert rugby union players were asked to perform DMs and NDMs in a real 1 vs. 1 duel. For each type of movement (DM^+, DM^-, NDM) different relevant orientation/reorientation parameters, medio-lateral displacement of the center of mass (COM), foot, head, upper trunk, and lower trunk yaw; and upper trunk roll were analyzed and compared. Results showed that COM displacement and lower trunk yaw were minimized during DMs while foot displacement along with head and upper trunk yaw were exaggerated during DMs (DM^+ and DM^-). This would suggest that the player is using exaggerated body-related information to consciously deceive the defender into thinking he will run in a given direction while minimizing other postural control parameters to disguise a sudden change in posture necessary to modify final running direction. Further analysis of the efficacy of deceptive movements showed how the disguise and deceit strate-

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doi:10.1016/j.humov.2009.12.004

gies needed to be carefully balanced to successfully fool the defender.

1. Introduction

Suddenly changing direction is achieved by implementing a whole body reorientation strategy. Numerous studies have analyzed various motor control and orientation in space strategies by examining how the coordination of the movement of the eyes, head, body, and limbs changes during a locomotor task (Crane & Demer, 1997; Hirasaki, Moore, Raphan, & Cohen, 1999; Imai, Moore, Raphan, & Cohen, 2001; Inman, 1966; Maurer, Kimmig, Trefzer, & Mergner, 1997; Mergner & Rosemeier, 1998; Moore, Hirasaki, Cohen, & Raphan, 1999; Winter, MacKinnon, Ruder, & Wieman, 1993). Generally, these studies have shown that during reorientation, the body, head, and eyes are coordinated according to a top-down strategy (Patla, Prentice, Robinson, & Neufeld, 1991), with priority being given to head re-alignment to allow gaze to be stabilized in space (Crane & Demer, 1997; Hirasaki et al., 1999; Moore et al., 1999; Pozzo, Berthoz, Lefort, & Vitte, 1991). Flanders, Daghestani, and Berthoz (1999), Hollands, Sorensen, and Patla (2001), as well as Pozzo, Berthoz, and Lefort (1990) and Pozzo, Levik, and Berthoz (1995), support this finding, suggesting that the stabilization of the head and eyes in space is necessary to provide a stable platform for coordinating entire body movement during locomotion. Controlling head movements in the horizontal plane while changing direction (Gibson, 1958; Grasso, Glasauer, Takei, & Berthoz, 1996; Hollands et al., 2001; Patla, Adkin, & Ballard, 1999) is therefore very important. Patla et al. (1999) also mentioned that the general body kinematic changes necessary for this reorientation concern the visual system and the control of the body's center of mass (COM) in the mediolateral (M/L) plane. The body COM in the M/L plane can be regulated through the placement of the supporting limbs and the control of the body pendulum by appropriate actions of the ankle, hip, and trunk muscles (MacKinnon & Winter, 1993; Winter, 1995). Placing the appropriate limb support to move the COM involves the abduction/adduction movement of the hips during the preceding step. The increased abduction or adduction activity of the hip will, respectively, increase or decrease the width of the step (Winter, 1995).

Two theories have been put forward concerning the regulation of the body as a pendulum. The first posits that the body is controlled as an "inverted pendulum" in the frontal plane with this being achieved through the modulation of the activity of the ankle muscles. However, as these muscles are quite weak and the inertia of the pendulum is large, this strategy has been shown to be ineffective (Winter, 1995) or may only be effective if the situation is not temporally constrained (Patla et al., 1999). The second theory claims that for a fast and efficient displacement of the COM, a hip and trunk muscle strategy, called the "hip strategy" (Horak & Nashner, 1986) is preferred (Patla et al., 1999). In this strategy, the body is controlled as a "double pendulum" by moving the lower limbs and upper body in opposite directions, allowing the movement of COM to the right or left during locomotion (Patla et al., 1999). This strategy enables a trunk roll movement in an opposite direction (Hollands et al., 2001).

The current work focuses on the mechanisms of changing running direction in a particular situation, namely an attacker vs. defender duel in rugby. This duel essentially involves an interaction of the motor strategies of the two players. To beat the defender, the attackers can try to perform a deceptive movement (DM), that is, to attempt to fool the defender into thinking they are going to run in one direction and then suddenly change direction at the latest possible moment. Although Jackson, Warren, and Abernethy (2006) make an essential distinction between the attempt made by a player to disguise his intentions by hiding the information that he is making available to the opposing player and the attempt to mislead an observer by offering false information (deception), these studies (Cañal-Bruland & Schmidt, 2009; Jackson et al., 2006; Sebanz & Shiffrar, 2009) have not analyzed the biomechanics of deception and disguise. To fill this omission, the present study will look at: (i) how segmental organization creates false information that leads the defender to believe that the attacker will run in a given direction; and (ii) how fundamental kinematic information is minimized or hidden to ensure that the attacker can make a sudden late change in running direction while preserving overall global stability of the body. Ultimately the timing of the control of the different body segments will ensure that the defender does not detect too early the deceitful intentions from the more relevant body-based information that will suggest final running direction. A detailed kinematic analysis of the attacker's actions will allow us to differentiate situations where the attacker is trying to deceive the defender with regard to future running direction (deceptive movements) from situations where no deception is involved and the attacker is simply going to change his running direction. In the case of deceptive movement the challenge for the attacking player is to make sure that the defender focuses his attention on the movement of the body that will convey deceptive information while disguising his true intentions by minimizing the main kinematic parameters that may betray body reorientation. Analyzing this balance between the biomechanics of deception and disguise makes the present analysis original.

The purpose of our study is to perform a biomechanical comparison of the changing direction strategies employed by attacking players during deceptive (DM) and non-deceptive movements (NDM) in a one vs. one situation in rugby. First, we will try to understand how biomechanical reorientation parameters are managed and balanced during DMs and NDMs. Second, we will try to further differentiate between effective DMs ("successful", DM^+) and ineffective DMs ("unsuccessful" DM^-). With respect to the two processes of deceit and disguise, the hypothesis that we endorse is that a biomechanical analysis of DM and NDMs will highlight exaggerated biomechanical parameters associated with deceit and minimized biomechanical parameters associated with disguise. Furthermore, concerning the efficacy of the DMs (DM^+ vs. DM^-), we suppose that successful DMs should balance deceitful information with attempts at disguise, while adhering to certain minimum/maximum thresholds for each, allowing the global movement to maintain a minimum level of credibility.

2. Methods

2.1. Participants and protocol

Eight expert amateur rugby union players (mean age 21.38 years; $SD = 1.18$), all playing in one of the French national leagues, took part in the experiment. Participants were invited to perform a real 1 vs. 1 duel where players took turns in being either the attacker or the defender. The aim for the attacking player was the same as in the game of rugby, namely to try to beat the defender by passing on his right- or left-hand side. In the duel the defender was told to try and stop the attacker by making a grab tackle. The defender was naïve as to the type of movement that the attacker was going to execute (DM or NDM). Indeed, as would be the case for a 1 vs. 1 duel in a real game of rugby the attacker had two choices to beat the defender, i.e., either by using a DM or a NDM. The attacker was free to choose which movement he selected to beat the defender. This made the duel more realistic and game-like where the attacker would respond as a function of the defender's actions to try and get past the defender.

By recording a real duel we had the advantage over previous studies such as that of Jackson et al. (2006), who did not have an attacker trying to beat a defender but merely an attacker who pretended to make a deceptive movement while approaching a video camera. This rendered the deceptive movements rather arbitrary and false, as the attacker did not have to respond to what the defender was doing; in other words, previous work did not capture the essence of the interaction between the two players' responses.

Both players started 15 m apart with each attacker being instructed to perform a total of 20 different attacking moves. To make up the 20 moves the participants were asked to make five moves where they would pass to the left of the defender by performing a deceptive movement (DM) to the right, five moves where they would pass to the right of the defender by performing a deceptive movement to the left, five simple directional changes (NDM, non-deceptive movements) to the left and five to the right (NDM) of the defender. Unlike the DMs, the NDMs did not require a second reorientation of the body (see Fig. 1).

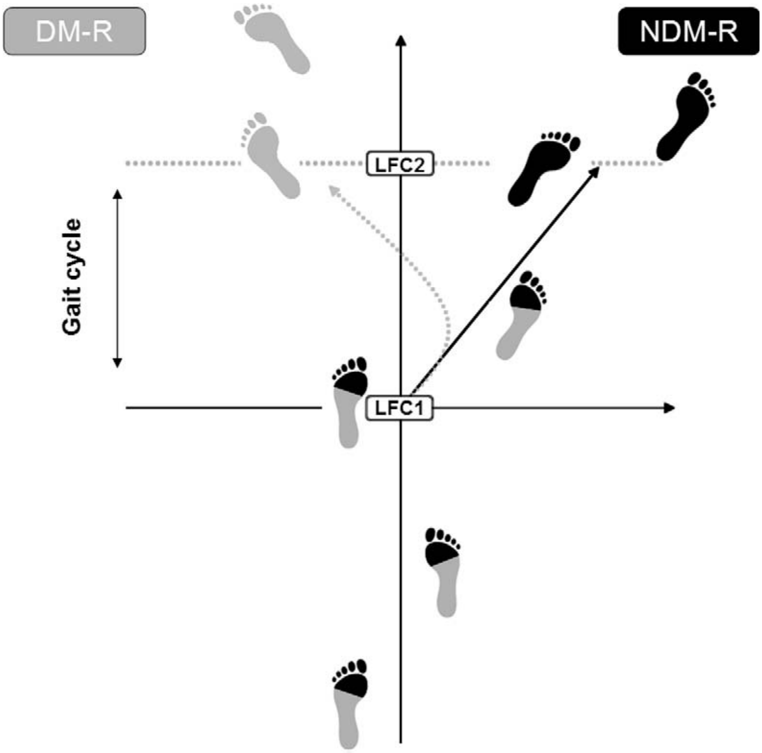

Fig. 1. A schematic representation of events during both a deceptive (DM-R) and a non-deceptive movement (NDM-R) where the first directional change is to the right. The interval of study was identified as a whole gait cycle between LFC1 and LFC2 (left foot contact 1 and 2).

2.2. Motion capture in situ

Motion capture was accomplished by means of an optoelectronic motion capture device Vicon MX (Oxford Metrics, Oxford, UK). Twelve high-resolution cameras (4 megapixels), running at a rate of 120 Hz, were positioned in a circle around the scene. The experiment took place in an indoor sports hall. To obtain more accurate readings from the markers by placing them on the skin or a stable surface, participants wore only rugby shorts, a headband, and training shoes. This minimized recording errors due to the movement of clothes such as a T-shirt. Twenty-eight reflective markers were placed on the following anatomical landmarks: sterno-clavicular joint, xiphoid process, 7th cervical vertebra, 10th thoracic vertebra, and for both hemi-bodies, occipital and frontal bones, gleno-humeral joint, lateral humeral epicondyle, ulnar styloid process, radial styloid process, anterior superior iliac spine, posterior superior iliac spine, lateral tibiale, lateral malleolus, heel, and head of the 2nd metatarsus. Reconstruction and labelling were performed using Vicon IQ software (Oxford Metrics) and computations were carried out using Matlab 6.5 (Mathworks, Natick, MA).

2.3. Selection and categorization of DMs

Deceptive movement (DM) is a strategy which aims to mislead the defender about the direction in which the attacker is going to run. An analysis of the defender's response can therefore be used as a means of validating the effectiveness of the DM. In other words, if during the execution of a DM to the right, the defender starts to move to the right, then it can be assumed that the attacker was successful in conveying false information to the defender through the configuration of their body segments before the second reorientation. More specifically, in terms of global motion, an effective DM (DM^+) will imply a medio-lateral displacement of the defender in the initial misleading direction given by the attacker's body configuration. To determine successful DMs from unsuccessful DMs we calculated the variations in the defender's COM in the transversal axis (this axis is determined from the attacker's displacement before the first orientation – further details are provided in Section 2.5) and categorized successful DMs (DM^+) when lateral displacements of the defender's COM exceeded 5 cm in the opposite direction to the final running direction. This value is in accordance with Raymakers, Samson, and Verhaar (2005), who showed that the excursion of the center of pressure was a maximum of 2.3 cm in the medio-lateral axis for a group of young healthy participants that were recorded while standing on a force plate. If the maximum excursion is 2.3 cm in this particular instance where no changes in direction were being instigated, we decided to take twice this value (5 cm medio-lateral displacement of the COM) as an adequate threshold for classifying intentional medio-lateral displacement. As a consequence, DMs with a COM displacement of the defender less than 5 cm were classified as being DM^- (ineffective DMs) and DMs that elicited a COM displacement of the defender greater than 5 cm were classified as DM^+ (effective DMs). For the eight participants tested, one player who played lock forward (usually number 4 or 5) and whose skill profile was more defensive than attacking, was not able to perform any effective DMs. His data were therefore eliminated. Furthermore, two other movements had to be eliminated because they fell outside the capture zone. This amounted to a total of 138 movements: 70 NDMs, 35 DM^+, and 33 DM^-. All three types of movement were analyzed with the results being presented in the following sections.

2.4. Interval of study

Movements were classified as: (i) non-deceptive movements to the right (NDM-R) or to the left (NDM-L), and (ii) deceptive movements to the right (DM-R) before a final running direction to the left and deceptive movements to the left (DM-L) before a final running direction to the right. NDMs (NDM-R and NDM-L) differed from DMs in that they elicited one single change in running direction while the DMs (DM-R and DM-L) represented two changes in running direction. These reorientations were encapsulated in a complete gait cycle that was defined as our interval of study (see Fig. 1). This interval started when the foot made contact with the ground before changing direction (LFC1: left foot contact 1 for DM-R and NDM-R; RFC1: right foot contact 1 for DM-L and NDM-L). LFC2 (and RFC2, respectively) was the second left foot (resp. right foot) contact of the cycle. LFC1 (or RFC1) was determined from the kinematic data of the markers placed on the foot. The contact was considered effective when the vertical velocities of either the heel or the head of the 2nd metatarsus marker equalled zero and the position was constant. The trajectories of all parameters were re-sampled to provide 100 equally spaced data points using a cubic spline interpolation between the time of LFC1/RFC1 and the time of the final support foot of the cycle (LFC2/RFC2). Note that for the NDM-R and DM-R the right foot was considered as the outside foot (OutFoot: OF) and the left foot was considered as the inside foot (InFoot: IF). The opposite notation was used for NDM-L and DM-L: OF is the left foot and IF is the right one.

2.5. Kinematic analysis

The following kinematic parameters were analyzed: head yaw, lower and upper trunk roll, and M/L displacement of the OF and the COM. The latter was calculated for both participants (attacker and defender) and obtained using the anthropometric table of Zatsiorsky, Seluyanov, and Chugunova (1990). All these parameters were calculated using a 3D frame of reference (Fs) that was specific for each movement. The origin of the Fs refers to the projected (COM) on the ground at the moment of LFC1 (or RFC1) respectively, with the vertical Z axis, the Y axis in line with the direction of the previous gait cycle, and the X axis perpendicular to the other two axes. For the Y axis, the direction was obtained from the linear regression of the COM trajectory (on the previous cycle before changing direction) on the XY plane of the world frame (F). The 3D coordinates originally obtained in F for both the attacker and the defender were reoriented to obtain new coordinates in Fs.

With respect to the global kinematic profile of all these parameters, a clear and obvious distinction needs to be drawn between the DMs and the NDMs. Indeed, although we observe a first reorientation

Table 1

Correlation coefficient (Pearson correlation, $p < .001$) and mean distance (±*SD*) (paired *t*-test, $p < .001$) between DM^{+}, DM^{-}, and NDM (R and L) for the 25% to R2-DM time period over: M/L displacement of COM and OF; yaw movement of head, upper trunk and lower trunk; and roll movement of the upper trunk.

	DM-R^{+}/NDM-R	DM-R^{-}/NDM-R	DM-R^{+}/DM-R^{-}	DM-L^{+}/NDM-L	DM-L^{-}/NDM-L	DM-L^{+}/DM-L^{-}
	Correlation (LFC1(or RFC1)/R2-DM) (Pearson correlation)					
COM M/L displacement (cm)	$r(36) = .985$, $p < .001$	$r(36) = .983$, $p < .001$	$r(36) = 1$, $p < .001$	$r(35) = .980$, $p < .001$	$r(35) = .970$, $p < .001$	$r(35) = .999$, $p < .001$
Head yaw (°)	$r(34) = .999$, $p < .001$	$r(34) = .999$, $p < .001$	$r(34) = 1$, $p < .001$	$r(26) = .976$, $p < .001$	$r(26) = .984$, $p < .001$	$r(26) = .998$, $p < .001$
Upper trunk Yaw (°)	$r(30) = 1$, $p < .001$	$r(30) = 1$, $p < .001$	$r(30) = 1$, $p < .001$	$r(25) = .994$, $p < .001$	$r(25) = .998$, $p < .001$	$r(25) = .987$, $p < .001$
Upper trunk roll (°)	$r(44) = .942$, $p < .001$	$r(44) = .943$, $p < .001$	$r(44) = 1$, $p < .001$	$r(52) = .939$, $p < .001$	$r(52) = .852$, $p < .001$	$r(52) = .978$, $p < .001$
OF M/L displacement (cm)	$r(54) = .993$, $p < .001$	$r(54) = .990$, $p < .001$	$r(54) = .999$, $p < .001$	$r(52) = .993$, $p < .001$	$r(52) = .986$, $p < .001$	$r(52) = .998$, $p < .001$
Lower trunk yaw (°)	$r(11) = -.998$, $p < .001$	$r(11) = -.964$, $p < .001$	$r(11) = .978$, $p < .001$	$r(14) = .836$, $p < .001$	$r(14) = -.782$, $p < .001$	$r(14) = -.978$, $p < 0.1$
	Mean distance ± SD (LFC1(or RFC1)/R2-DM) (paired t-test)					
COM M/L displacement (cm)	-10.643 ± 9.037 $t(70) = -7.066$, $p < .001$	-11.760 ± 9.717 $t(70) = -7.261$, $p < .001$	1.117 ± 0.694 $t(70) = 9.657$, $p < .001$	10.818 ± 9.264 $t(68) = 6.909$, $p < .001$	11.986 ± 10.037 $t(68) = 7.065$, $p < .001$	-1.168 ± 0.784 $t(68) = -8.811$, $p < .001$
Head Yaw (°)	3.584 ± 0.515 $p < .001$ (Wrt)	6.052 ± 0.265 $t(66) = 133.325$, $p < .001$	-2.467 ± 0.548 $t(66) = -26.243$, $p < .001$	-7.649 ± 0.757 $t(50) = -51.494$, $p < .001$	-4.871 ± 1.955 $t(50) = -12.704$, $p < .001$	-2.777 ± 1.857 $t(50) = -7.625$, $p < .001$
Upper Trunk Yaw (°)	10.612 ± 0.327 $t(58) = 177.579$, $p < .001$	12.573 ± 1.395 $t(58) = 49.381$, $p < .001$	-1.962 ± 1.223 $t(58) = -8.782$, $p < .001$	-12.684 ± 1.229 $t(48) = -51.609$, $p < .001$	-7.771 ± 0.604 $t(48) = -64.346$, $p < .001$	-4.913 ± 1.795 $t(48) = -13.689$, $p < .001$
Upper Trunk Roll (°)	7.174 ± 3.527 $p < .001$ (Wrt)	7.210 ± 1.533 $p < .001$ (Wrt)	-0.0360 ± 2.179 $t(58) = 177.579$, $p = .913$	-8.092 ± 4.513 $p < .001$ (Wrt)	-9.774 ± 1.847 $t(102) = -38.163$, $p < .001$	1.683 ± 3.701 $p < .001$ (Wrt)
OF M/L displacement (cm)	18.631 ± 3.782 $t(106) = 36.202$, $p < .001$	16.819 ± 1.810 $p < .001$ (Wrt)	1.812 ± 2.904 $p < .001$ (Wrt)	-16.568 ± 2.217 $p < .001$ (Wrt)	-13.707 ± 2.166 $t(102) = -45.628$, $p < .001$	-2.861 ± 1.461 $p < .001$ (Wrt)
Lower Trunk Yaw (°)	-5.76 ± 0.467 $t(20) = -38.441$, $p < .001$	-4.47 ± 0.728 $t(20) = -20.363$, $p < .001$	-1.290 ± 0.246 $t(20) = -17.387$, $p < .001$	7.477 ± 0.115 $p < .001$ (Wrt)	10.184 ± 1.192 $t(26) = 31.978$, $p < .001$	-2.707 ± 1.147 $t(20) = 1.147$, $p < .001$

(R1) around LFC1 for both types of movement (DMs and NDMs), we only observe a second reorientation for the DMs (R2-DM). These reorientations (R1 and R2-DM) are considered effective when the derivate sign changes with a slope of ±10% (absolute value of the derivate >0.1). This threshold allows us to identify real effective initiation of a reorientation and not just low oscillations. Thus, all these reorientations are relative to each movement and each analyzed parameter. The values of R1 and R2-DM may then be different for each parameter and each movement. Note that for the foot displacement when OF is in contact with the ground, only the IF is able to initiate the second reorientation which explains why R2-DM is calculated from the IF M/L displacement.

These reorientations form the basis of the comparisons between the DMs and the NDMs. First, they provide the instants when the reorientation appears for all the parameters in each movement. For example, if there is an early first reorientation then there is enough time to perform a second reorientation giving rise to a DM. Second, they refine the interval of study that is being used to compare the DMs and the NDMs. For instance, the attacker needs to provide the defender with false information *before* the second reorientation. With this in mind we compared the kinematic patterns of all the parameters in the interval between LFC1 and R2-DM. Consequently, LFC1 is the key reference event that allows us to compare movements with R2-DM being used to demarcate the interval of study. R2-DM, which is computed for DMs only, can be used to compare the same parameters for the different movements as all of them have been re-sampled in the same way based on the gait cycle.

2.6. Statistical analysis

For all data we calculated the correlation coefficient (Pearson correlation coefficient r, $p < .001$) between DMs and NDMs on the interval between LFC1 (or RFC1) and the beginning of the second reorientation during the DMs (R2-DM, for DMs only). When the correlation was higher than 90% the mean distance between the two curves (delay on the Y axis) at the same interval (between *LFC1 or RFC1* and *R2-DM*) on pairs of NDM-DM values were compared using a paired t-test ($p < .001$). When the normality test failed, we used a Wilcoxon signed ranks test (reported in the Table 1 by *Wrt*). We then calculated the time taken to initiate this first reorientation (R1) for each parameter (Student t-test, $p < .05$). In addition, in order to examine the effect of the movement type (DM^+, DM^-, NDM) on the different biomechanical parameters, the onset of R1 during the first reorientation was analyzed using a one-way analysis of variance (ANOVA). As appropriate, Tukey's HSD post hoc tests ($p < .05$) were carried out to further examine where the significant effects between groups were. For both DM groups (DM^+ and DM^-) we used a Student t-test ($p < .05$) to compare the delay of the second reorientation (R2-DM).

3. Results

3.1. DM vs. NDM

3.1.1. Kinematic pattern and mean distance

This first part of the results is a correlation analysis which aims to compare the dynamic pattern of each parameter during the first orientation (DMs vs. NDMs) given by the attacker. This preliminary step needs to be carried out in order to detect where the differences between the two different types of movement may lie. For example, a high correlation coefficient would indicate that the given parameters did not deviate sufficiently to account for potential differences between the kinematics of DMs and the NDMs. However, a lower correlation coefficient for a specific parameter could point to a parameter that is essential in distinguishing DMs from NDMs.

The results showed that in the interval between LFC1 (or RFC1) and R2-DM, all the different kinematic parameters (except for all lower trunk yaw comparisons) yielded correlation coefficients consistent on both sides (right and left) and higher than .94 ($p < .001$) (see Table 1). It should however be noted that for the upper trunk roll the correlation between DM-L^- and NDM-L was still .852, which can be considered as a very high correlation and globally in accordance with the rest of the results. One result concerning the COM parameter has a particularly high correlation coefficient (for example,

$r(36) = .985$ for DM-R$^+$/NDM-R and $r(32) = .980$ for DM-L$^+$/NDM-L, $p < .001$) despite an early differentiation of the curves for DMs and NDMs (see Fig. 2). On the contrary, lower trunk yaw does not have any recognizable kinematic pattern on either side (right and left) when comparing DMs and NDMs ($r(11) = -.998$ for DM-R$^+$/NDM- R and $r(14) = .836$ for DM-L$^+$/NDM-L). Indeed, it seems that the lower trunk only presents simple and irregular low oscillations without showing any particular and obvious orientation. For this reason we decided not to include the reorientation delay or the chronological order of this parameter when discussing reorientation strategy. Despite these patterns in the kinematics, our results show in the same interval (25% – R2-DM) significant differences in mean distances

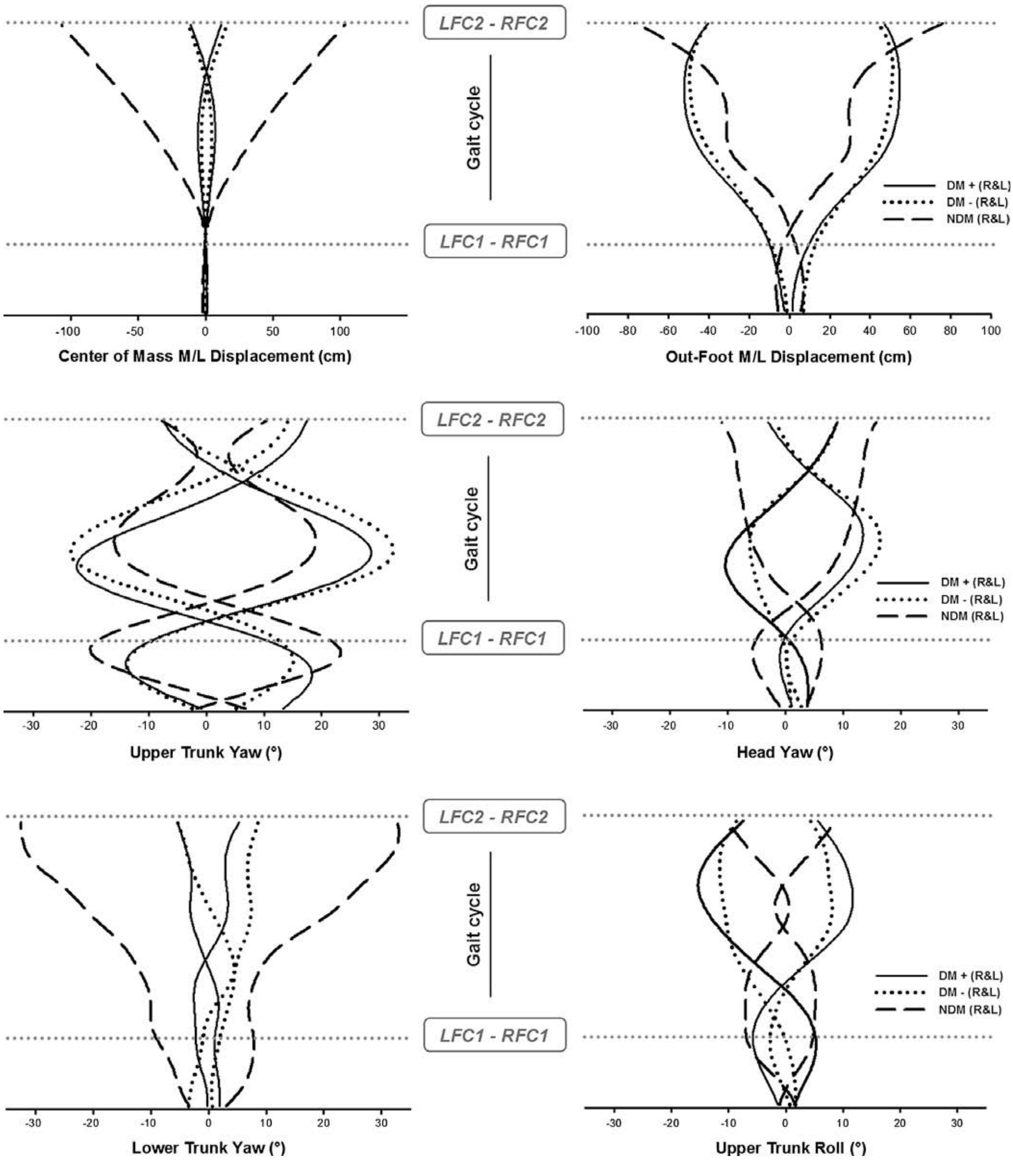

Fig. 2. Normalized time profiles for the transition stride (LFC1 to LFC2 or RFC1 to RFC2) over: M/L displacement of the COM and OF; yaw movement of the head, upper trunk and lower trunk; and roll movement of the upper trunk. The three types of movement are represented on each graph: DM$^+$, DM$^-$, and NDM.

between certain kinematic parameters (DMs vs. NDMs) (see Table 1). When comparing the DMs$^+$ vs. NDMs and DMs$^-$ vs. NDMs two of the kinematic parameters were found to be minimized in the M/L plane when performing a DM compared to a NDM. These were the displacement of the COM in the M/L plane (DM-R$^+$ vs. NDM-R mean distance = -10.643 ± 9.037; $t(70) = -7.066$, $p < .001$; DM-R$^-$ vs. NDM-R mean distance = -11.760 ± 9.717; $t(70) = -7.261$, $p < .001$; similar results for DM-L and NDM-L) and the lower trunk yaw (DM-R$^+$ vs. NDM-R mean distance = -5.76 ± 0.467; $t(20) = -38.441$, $p < .001$; DM-R$^-$ vs. NDM-R mean distance = -4.47 ± 0.728; $t(70) = -20.363$, $p < .001$; similar results for DM-L and NDM-L). All other kinematic parameters were found to increase during R1 (see Table 1).

3.1.2. Delay and strategies of reorientation: R1 and R2-DM

As indicated by the minus signs in Tables 2a and 2b, all the reorientations R1 of the different kinematic parameters were initiated before LFC1 and RFC1 (except for NDM upper trunk roll and DM$^-$ COM M/L displacement). The ANOVA revealed significant differences across DMs$^+$, DMs$^-$, and NDMs for the COM M/L displacement, $F(2, 137) = 7.893$, $p < .001$, $\eta_p^2 = .104$, and for the upper trunk yaw, $F(2, 137) = 6.543$, $p < .01$, $\eta_p^2 = .088$. The Tukey's HSD post hoc test analysis showed that the upper trunk yaw was reoriented (at R1) significantly earlier during the DM$^+$ than during the NDM ($p < .001$) and that the COM was reoriented significantly sooner for the NDMs when compared to DM$^+$ ($p < .05$) and DM$^-$ ($p < .001$).

Moreover, we can see a quasi-duplicate reorientation strategy during the first reorientation between DM$^+$ and NDMs (see Fig. 3). Only the COM differs by being reoriented earlier for the NDMs compared to DM$^+$. With the exception of the COM the chronological order of the appearance of the different parameters at R1, namely: OF M/L displacement; upper trunk yaw/head yaw (quite similar) and lastly upper trunk roll, is the same for both these types of movement. For the DMs$^-$ two main differences can be highlighted, namely, the significantly later orientation of the COM after the LFC1-RFC1 and the non-significant but obvious earlier orientation of the upper trunk roll compared to the NDMs.

3.2. DM$^+$ vs. DM$^-$

3.2.1. Kinematic pattern and mean distance

For all the comparisons between DMs and NDMs, except for the lower trunk yaw ($r(11) = .978$ for DM-R$^+$/DM-R$^-$ and $r(14) = -.978$ for DM-L$^+$/DM-L$^-$) all the parameters show a high and consistent correlation on both sides (right and left) (see Table 1). All the mean distances between DM$^+$ and DM$^-$

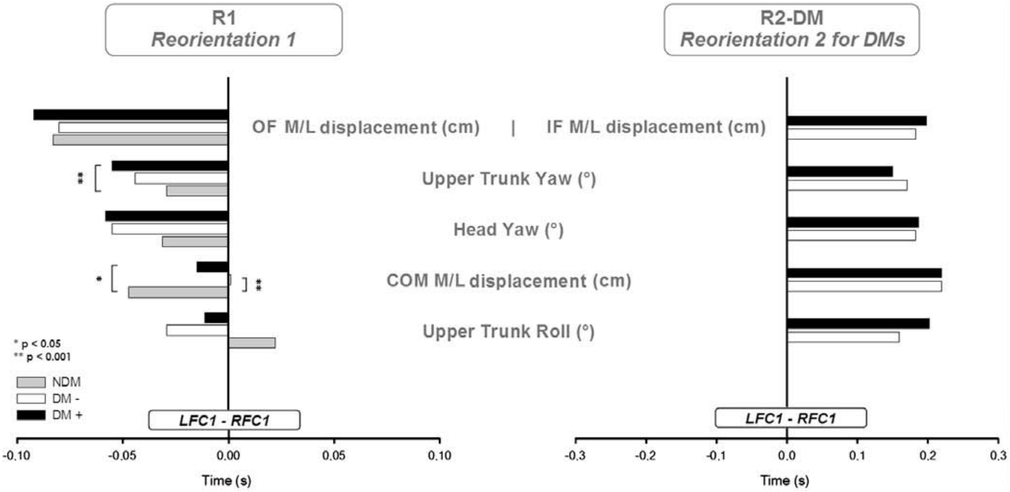

Fig. 3. Time of initiation of reorientation 1 and 2 (R1 and R2-DM) before or after LFC1 (or RFC1) in seconds (s) for: M/L displacement of COM and OF; yaw movement of the head and upper trunk; and roll movement of the upper trunk.

Table 2a

Mean delay of reorientation (±*SD*) (Student *t*-test, $p < .05$) of the M/L displacement of COM and OF; yaw movement of the head and upper trunk; and roll movement of the upper trunk between DM+, DM$^-$ and NDM for R1.

	DM$^+$	DM$^-$	NDM	DM$^+$/DM$^-$	DM$^+$/NDM	DM$^-$/NDM
	Mean delay ± SD (R1) (one-way ANOVA)					
COM M/L displacement (cm)	−0.015 ± 0.052	0.001 ± 0.054 $F(2, 137) = 7.893$, $p < .001$	−0.047 ± 0.068	Diff. of means = 0.0157 $p = .536$	Diff. of means = 0.0323 $p < .05$	Diff. of means = 0.048 $p < .001$
Head yaw (°)	−0.058 ± 0.048	−0.055 ± 0.058 $F(2, 137) = 2{,}33$, $p = .101$	−0.031 ± 0.081	–	–	–
Upper trunk yaw (°)	−0.055 ± 0,036	−0.044 ± 0.031 $F(2, 137) = 6.543$, $p < .01$	−0.029 ± 0.037	Diff. of means = 0.0114 $p = .371$	Diff. of means = 0.0256 $p < .001$	Diff. of means = 0.0142 $p = .371$
Upper trunk roll (°)	−0.011 ± 0.072	−0.029 ± 0.08 $F(2, 137) = 2.514$, $p = .085$	0.022 ± 0.144	–	–	–
OF M/L displacement (cm)	−0.092 ± 0.053	−0.08 ± 0.053 $F(2, 137) = 0.254$, $p = .776$	−0.083 ± 0.087	–	–	–

Table 2b
Mean delay of reorientation (±*SD*) (Student *t*-test, $p < .05$) of the M/L displacement of COM and OF; yaw movement of the head and upper trunk; and roll movement of the upper trunk between DM$^+$, DM$^-$ and NDM for R2-DM.

	DM$^+$(R and L)	DM$^-$ (R and L)
Mean delay ± SD (R2-DM) (Student t-test)		
COM M/L displacement (cm)	0.219 ± 0.081 $t(132) = 0.013$, $p = .990$	0.219 ± 0.116
Head yaw (°)	0.187 ± 0.072 $t(132) = 0.212$, $p = .833$	0.183 ± 0.088
Upper trunk yaw (°)	0.15 ± 0.058 $t(132) = -1.34$, $p = .185$	0.17 ± 0.068
Upper trunk roll (°)	0.202 ± 0.121 $t(132) = 1.458$, $p = .149$	0.159 ± 0.121
OF M/L displacement (cm)	0.198 ± 0.149 $t(132) = 0.421$, $p = .675$	0.183 ± 0.15

show very small, but significant differences for all the parameters (except for upper trunk roll). Nevertheless, the only parameters that were found to be homogeneous (always exaggerated or always minimized) on both sides (right and left) are the COM M/L displacement and the OF displacement, both of which are minimized during DM$^-$ compared to DM$^+$ (see Table 1). For all the other parameters no specific trends are observed, due to the inequality in differences observed on both sides (exaggerated for one side and minimized for the other one).

3.2.2. Delay and reorientation strategies: R1 and R2-DM

As the results show in Tables 2a and 2b there are no significant differences between the reorientation delay for DM$^-$ and DM$^+$. Nevertheless, the data highlight that all the parameters (except the upper trunk roll) are reoriented later for DM$^-$ compared to DM$^+$. Although almost all the different kinematic parameters were initiated before LFC1 and RFC1, it should be noted that this is not the case for the COM M/L displacement for DM$^-$ which is oriented after foot floor contact (LFC1 or RFC1). With respect to R2-DM which concerned only the deceptive movements, no significant differences were found.

Consequently, we can see that similar to the comparison between DMs and NDMs there is an almost identical reorientation strategy during the first reorientation between DM$^+$ and DM$^-$ (see Fig. 3). The only difference is the upper trunk roll which is the last parameter orientated during DM$^+$ and the last but one during DM$^-$. For the DM$^{+,}$ the order of appearance of R2-DM for the IF displacement (4th instead of 1st) changes when compared to the order of appearance of R1, The upper trunk yaw is also more clearly reoriented earlier than the head yaw. During R2-DM, no significant time differences for the reorientation of all the kinematic parameters were found when comparing DM$^+$ and DM$^-$.

4. Discussion

The significant correlations observed between DMs and NDMs at R1 underline the fact that there is a common kinematic pattern for the different biomechanical parameters during this approach phase. Only lower trunk yaw, which represents pelvic movement, shows no recognizable kinematic pattern when comparing DMs and NDMs. In other words, this means that the lower trunk yaw does not show any regular oscillation and consequently no obvious orientation phase. Slocum and Bowerman (1962) were the first authors to emphasize the biomechanical function of the lumbar pelvis while running by showing that it was the key to postural control. It is often recognized as an essential biomechanical constraint for body stability and the development of final posture. But given that DMs are characterized by a second change in running direction, which occurs just after the first, the role of the pelvis for global body reorientation must be minimized in order to maintain balance. The results of the mean distance between the DM (DM^+ and DM^-) and NDM curves support our initial hypothesis. Indeed, the strategy of changing direction during DMs seems to involve two different processes: (i) the use of exaggerated false parameters to mislead the defender into thinking the attacker will run in the opposite direction, and (ii) the minimization of other parameters in order to keep postural stability flexible so that the attacker can still change his final running direction. The minimization of the displacement of the COM in the M/L plane and the lower trunk yaw reflects the disguise attempts, but yet respects the postural control constraints necessary to ensure that the desired final direction can be attained. On top of these stability constraints, the movements of the limbs and the trunk are organized, reflecting the intention to deceive by providing false final directional information to the defender. The most significant angular changes are found in the upper trunk that represents the direction of the shoulders. In other words the attackers exaggerate the shoulders movement in the direction opposite to where they will run. This parameter also attracts the defender's attention and encourages them to focus on the upper body instead of the pelvic region that may give more credible information about future running direction. Indeed, as it represents an important part of the total body mass, it is expected to play a major role in the reorientation of the COM and it is not surprising that the defender attempts to use this information to anticipate future running direction. These types of strategies have already been shown in other sports such as tennis. For example, Pollick, Fidopiastis, and Braden (2001) have shown that exaggeration of critical kinematic information could modulate the recognizability of tennis-serve style. Therefore, from a performance perspective, it would appear that the kinematical manipulation of particular body-based information can be used to deceive an opponent and gain a competitive edge (Huys et al., 2009; Williams, Huys, Cañal-Bruland, & Hagemann, 2009).

In this work, the attacking player's skill lies in his ability to control his body movements in such a way that the defender believes he will run in that direction. In other words the initial direction in which the COM is orientated does not necessarily represent final running direction. The aim for the attacker is to present a segmental organization which will deceive the defender by exaggerating upper body information revolving around the initial false COM direction, while limiting the key factors that will indicate final running direction. The early R1 reorientation (except for the COM M/L displacement) for the DM^+ compared to the NDMs highlights the deceptive part of the attacker's action, namely to provide false running direction information early enough so that they still have time to change direction again. Apart from the COM and the yaw of the lower trunk both defined as attempts at disguising final running direction during DMs, the same chronological order of reorientation of the different parameters during the first global reorientation for DM^+s and NDMs can be observed, although it is later for the NDMs.

For all movements, the strategy, however, is not a top-down strategy where the head initiates the reorientation. Instead it can be considered as a bottom-up strategy where the displacement of support comes first, followed by a reorientation of the upper trunk and head (almost simultaneously during R1). According to the results of Patla et al. (1999) and Hollands et al. (2001), we find the upper trunk roll movement in the opposite direction to the direction of displacement. However, it comes last (except for DM^-) in the reorientation strategy (R1), which suggests a lesser influence for changing direction in this type of task when compared to locomotion (Patla et al., 1999). Finally, the main difference between DMs and NDMs is the later, and not really effective, reorientation of the COM. The bottom-up strategy should allow a reorientation of COM in DMs, but as we have seen before, its displacement is countered by a smaller oscillation and orientation of the pelvis to maintain postural stability and to keep the possibility of changing final running direction. Furthermore, during R2-DM the displacement of IF does not initiate reorientation. This can be explained by a very long OF contact time due to a sudden and significant reorientation which is needed for the whole body. In this case, where the situation has critical temporal constraints and requires an efficient and fast displacement of COM, we find evidence to support the results of Patla et al. (1999) and the double pendulum theory or "hip strategy".

Moreover, from the above findings we would suppose that the most effective DMs would involve deceiving the defender by maximizing the exaggerated kinematic parameters concerning the action while disguising the intention by minimizing the important information concerning body reorientation. It should however be noted that the goal is not to over-exaggerate or over-minimize the kinematic patterns concerning the action. For example, our results have shown that for the DM^- conditions an over-minimization of two key parameters namely OF displacement and COM M/L, will translate into insufficient body movement in the wrong direction, limiting the credibility of the deceptive movement. In this case the results suggest that if the balance between disguise and deceit for DM^- is not respected, the overall goal, namely get the defender to move in the wrong direction, is not achieved. Successful DMs should therefore balance disguise and deceit but limit them to a minimum/maximum threshold for each that still allows global movement to maintain a level of credibility. Indeed as we have seen, if DM^- presents an even balance of minimization of the COM M/L displacement on both sides they also mainly reveal a very late first orientation of this parameter compared to NDMs. In other words, the over-minimization of the COM M/L displacement during DM^- creates a too big difference between disguised and deceitful actions, thus reducing the credibility of the movement. In addition, the late orientation of this main parameter is not in concordance with all the others parameters, reducing the "synergy" between them and as a result the believability of the movement.

To conclude, we show that the different DM and NDM strategies are only inherent in the final running direction and in the biomechanical constraints that represent the placement of the pelvis for the orientation of the COM and postural control. First, we found that the first reorientation R1, present in all cases apart from lower trunk yaw and displacement of the COM, is an example of a bottom-up strategy, whereas R2-DM, which requires a critical and extremely sudden reorientation, can be understood as an example of a hip or double pendulum strategy. Second, we found that the "value" of the parameters (exaggerated or minimized) are in themselves not enough to understand the success of a deceptive action. To catch the attention of the defender during a DM, the "synergy" and the consistent balance between both types of parameters need to be taken into account.

Consequently, and from a performance perspective, the most effective deceptive movement should maximize or exaggerate the parameters that represent false information about future running direction, while minimizing or disguising the parameters that are key to reorient the body in the intended final running direction. This being said we have also shown that a certain consistency and synergy between disguise and deceit is required to ensure a successful action. Too large a discrepancy between the two elements (disguise and deceit) or too long a delay between the reorientation of body segments as was found for DMs^-, can decrease the credibility and success of the movement and can allow the defender to see that it is indeed a deceptive movement the attacker is trying to perform. Consequently, two further steps necessary to better understand deceptive movement are: (i) from a biomechanics perspective, quantifying the kinematical variance within which a deceptive movement is deemed successful, and (ii) from a perception perspective, identifying the perceptual information that the defending players attend to in order to make correct anticipatory judgements about the future running direction.

Acknowledgments

This study was partially supported by the International Doctoral College of the European University of Brittany and the British Council Alliance Travel fund scheme.

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