KINETIC ANALYSIS OF DIFFERENT RUNNING STARTS: IMPACT ON FORWARD CENTER OF MASS ACCELERATION AND PERFORMANCE

Nicolas Termoz, Ph.D[1], Kevin Lissajoux, M.Sc[1], Jean Slawinski, Ph.D[1]

Centre de Recherche sur le Sport et le Mouvement – EA 2931. Université de Paris Ouest – Nanterre – La Défense, 200 avenue de la république 92000 Nanterre, France.[1]

In this study, three running starts allowing more or less large shifts of the centre of pressure (CoP) were compared in order to assess their impact on the forward acceleration of the centre of mass (CoM) and on the performance of a short distance run. Temporal and biomechanical parameters were calculated from CoP data in eighteen subjects. Our results suggested that an increase of the base of support by moving backward the CoP quickly after the start signal has a positive impact on the performance on short distance runs.

KEY WORDS: Sprint start; Centre of pressure; Acceleration; Biomechanics

INTRODUCTION: In gait initiation tasks, it has been demonstrated that preparatory movements precede the execution of the first step from a quiet standing posture. These anticipated postural adjustments mainly produce a backward shift of the centre of pressure (CoP) associated with a forward acceleration of the whole body centre of mass (CoM). A second integral of this acceleration yield the trajectory of the CoM that could be interpreted relative to the CoP in either the anterior/posterior (A/P) or the medial/lateral (M/L) directions (Brenière, Do, & Bouisset, 1987). According to the inverted pendulum model (Winter et al., 1995), the greater and the faster the backward shift of the CoP relative to the vertical projection of the CoM (CoP-CoM), the greater the forward acceleration of the CoM. This biomechanical principle has been extended to more than one segment inverted pendulum (Termoz, Martin, & Prince, 2004). The inverted pendulum model has been also been applied in sprint start with a good accuracy (Natta & Breniere, 1997). However, in this preliminary study, the authors only modified the position of the CoM because the sprinter started in starting blocks. In team sports, contrary to sprint start, the player can adopt different kinds of starts and can modify the position of the CoM as well as the position of the CoP. These starts, by authorizing shorter or greater CoP displacements should have a direct impact on the forward acceleration of the CoM. However, to date, no study has assessed the impact of the scalar distance at a given time between the CoP and CoM (CoP-CoM) from different starts on the whole body acceleration. This modification of the CoP-CoM should have a direct impact on the performance on the start and successive steps (Nagahara, Matsubayashi, Matsuo, & Zushi, 2014)
Therefore, the aim of the present study is to manage the CoP displacements by adopting different starts in order to assess their impact on the forward acceleration of the CoM and on the performance of a short distance run.

METHODS: Eighteen physically active men (24.4 ± 4.0 years; 176.2 ± 7.0 cm; 73.3 ± 9.64 kg) gave their informed written consent to participate in the study. After warm-up, each subject realised three different kinds of start: 1) A standing parallel start (PS), 2) a standing false start (FS) and 3) a crouch three points start (3PS). Each start begins with the feet parallels but the first movement following the start signal gradually increased the backward displacements of the CoP. In PS, the first movement is to forward one leg. The trunk, the hip and the knee joints were bended in order to transfer the vertical projection of the CoM close to the anterior limit of the base of support and to increase backward displacements of the CoP. In FS, moving one foot backward, following the start signal, artificially increases the backward shift of the CoP. Finally, in 3PS a crouch start without starting blocks was analysed. It was performed with one hand on the ground and both feet remaining parallels. In

this condition, removing the hand on the ground creates a large backward displacement of the CoP. In each condition, the subjects must realise the best performance on a five meters run. The time (T_{5m}) was measured with photocells (Brower timing system, Draper, USA). A visual signal gave the start and triggered the chronometer. For each condition, the three best trials (best performance over five meters) were used for further analyses. All starting conditions were randomised to avoid any fatigue effects.
A force plate AMTI (Watertown, USA; 1200 x 600 mm, 200 Hz) was used to compute the accelerations of the CoM and to measure the shifts of the CoP from the ground reaction forces and moments. The A/P velocity of the CoM was calculated from its A/P acceleration.
The temporal and biomechanical parameters considered for this study were (Fig. 1) (Couillandre, Brenière, & Maton, 2000)): (i) the time (t_0) of the onset of the first mechanical phenomena; the time (t_{BW_CoP}) of the peak amplitude of the backward shift of the CoP; the time (t_{TOFF1}) of Toe Off of the stepping foot; the time (t_{TOFF2}) of Toe Off of the trail foot, (ii) the peak amplitude (BW_CoP) of the backward shift of the CoP with respect to the average initial position of the CoP at t0; the scalar distance at a given time between the COP and COM (CoP-CoM) at t_{BW_CoP} (iii) the A/P acceleration of the CoM at t_{BW_CoP} and (IV) the A/P velocity of the CoM at t_{BW_CoP}, t_{TOFF1} and t_{TOFF2}. All computation procedures were performed using Matlab Software (The Mathworks, Inc).

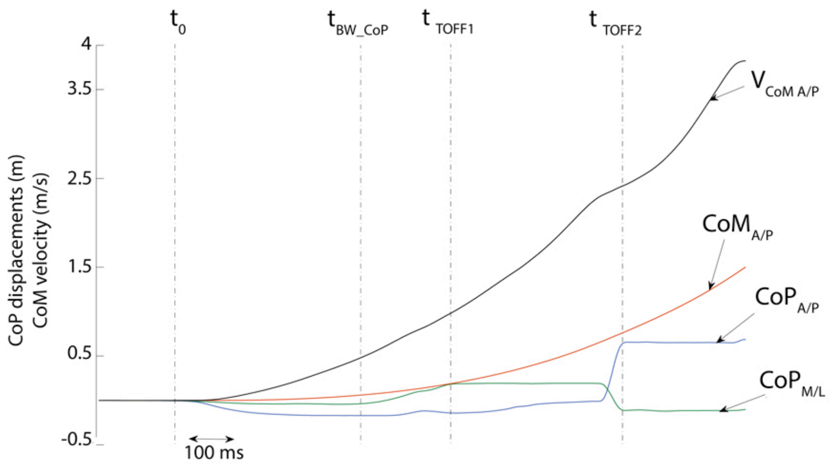

Fig.1: Recording of the biomechanical parameters during a standing parallel start; one trial, one subject, normal speed for each situation.

One-way ANOVAS were performed to compare the three conditions for each biomechanical and temporal parameter. The statistical significance level was set at p less than .05, and Newman-Keuls post hoc analyses were conducted when necessary. To quantify the relationship between the CoP-CoM variable and the horizontal acceleration of the CoM, Pearson's coefficients of correlation (r) were calculated.

RESULTS: The biomechanical and temporal parameters calculated are reported in table 1. The best performance is obtained with a 3PS condition whereas the poorest are for the PS condition. A significant difference between each condition was found for the backward shift of the CoP. These displacements were larger for the FS condition than for all the others, followed by the 3PS and PS conditions. The CoP-CoM variable followed the same tendencies. The forward acceleration of the CoM at t_{BW_CoP} was significantly larger in the FS and 3PS conditions with respect to the PS condition. These values seemed to be related to those obtained for the CoP-CoM variable. Indeed, the coefficients of correlation calculated at t_{BW_CoP} between the CoP-CoM variable and the forward horizontal acceleration of the CoM confirmed this interpretation ($r=-0.62$ for PS ($p<0.05$); $r=-0.25$ for FS (NS) and $r=-0.47$ for 3PS($p<0.05$).

Table 1: Biomechanical and temporal parameters calculated for each condition: PS: Parallel start; FS: False start; 3PS:3 points start. Mean(± sd). * p<0.05 with respect to others conditions; ° p<0.05 with respect to PS; + p<0.05 with respect to FS; ‡ p<0.05 with respect to 3PS

Parameters	PS	FS	3PS
T_{5m} Performance (s)	1.97 (±0.10)$^{+}$‡	1.83 (±0.10)*	1.74 (±0.10)*
BW_CoP (m)	-0.14 (±0.04)*	-0.40 (±0.06)*	-0.31 (±0.08)*
CoP-CoM (m)	-0.21 (±0.06)*	-0.48 (±0.07)*	-0.38 (±0.07)*
A_{CoM} at t_{BW_CoP} ($m.s^{-2}$)	2.43 (±0.81)*	7.31 (±1.66)*	6.10 (±1.44)*
V_{CoM} at t_{BW_CoP} ($m.s^{-1}$)	0.47 (±0.18)*	0.83 (±0.36)°	0.88 (±0.15)°
V_{CoM} at t_{TOFF1} ($m.s^{-1}$)	0.87 (±0.33)*	1.73 (±0.31)*	1.18 (±0.22)*
V_{CoM} at t_{TOFF2} ($m.s^{-1}$)	2.10 (±0.42)$^{+}$	2.86 (±0.39)*	2.18 (±0.34)$^{+}$
t_{BW_coP} (ms)	406.3 (±98.1)‡	455.8 (±76.4)‡	306.5 (±62.8)*
t_{TOFF1} (ms)	566.1 (±96.2)‡	592.3 (±72.9)‡	357.9 (±61.6)*
t_{TOFF2} (ms)	847.9 (±85.6)‡	815.1 (±63.0)‡	543.9 (±67.7)*

Otherwise, the results reported that the forward CoM velocity increased for each condition between the t_{BW_CoP} and t_{TOFF2}, when the subjects left the force plate. Fig. 2 reported the temporal parameters calculated for each condition. As depicted, all temporal parameters in the 3PS condition were significantly shorter than in the others conditions. More obviously, it appeared that the t_{TOFF2} in the 3PS condition was even shorter than the t_{TOFF1} of all others conditions. For the PS and FS conditions, no significant difference was found. However, our results highlighted a delay for the FS at t_{BW_CoP} with respect to the PS condition, which was caught up at t_{TOFF2}.

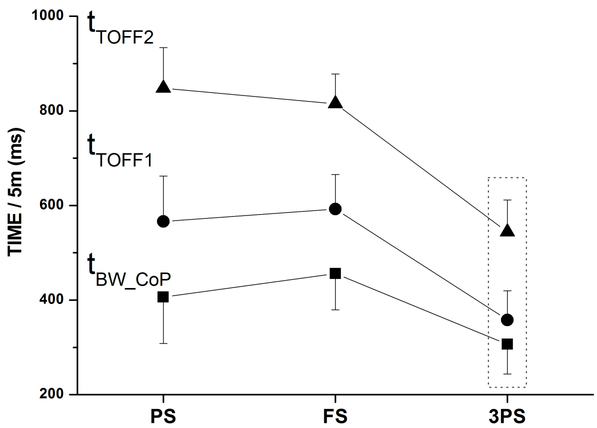

Fig.2: Temporal parameters for each start. Mean and sd. t_{BW_CoP}: Time to reach the peak amplitude of the backward shift of the CoP; t_{TOFF1}: Time of Toe Off of the stepping foot; t_{TOFF2}: Time of Toe Off of the trail foot. Doted rectangle: 3PS condition significantly different from the others conditions for each temporal parameter.

DISCUSSION: The aim of the present study was to manage the CoP shifts by adopting different start condition in order to assess their impact on the forward acceleration of the CoM and on the performance of a short distance run. Our results showed that the PS is the worst condition on a short distance sprint. This result is in accordance with those obtained by Frost & Cronin (2011). In contrast, the best performance is reached with the 3PS rather than with the FS, as it was suggested by Kraan, Van Veen, Snijders, & Storm (2001). Therefore, the best performances were reached in the condition that allowed the largest backward shift of the CoP. However, the correlations partially confirmed this interpretation. Therefore, others factors, such as mechanical power (Bezodis NE, Trewartha G, 2008) or the mean ratio of

forces applied onto the ground (Morin, Edouard, & Samozino, 2011) should explain this point. Otherwise, the timings of the temporal parameters were significantly shorter in the 3PS condition than for the others. This result is explained by the necessity to quickly counterbalance the large gravitational torque created when the subjects removed their hand in order to avoid the fall. Similar results were obtained by Do, Breniere, & Brenguier (1982) in a study assessing balance recovery from different leaning forward standing postures. The authors reported quicker balance recovery for the most destabilising postures.
When comparing the PS and the FS, our results suggested that despite an initial delay due to the backward displacement of the foot in FS, the performance was better than for the PS. This result might be explained by the greater horizontal acceleration of the CoM created by a large backward shift of the CoP in the FS condition. Therefore, the horizontal forward acceleration of the CoM as well as the horizontal velocity of the CoM was strongly higher for each temporal parameter calculated in the FS than in the PS. This interpretation is in line with the study by Brenière & Do (1986), which found an increase of the CoM velocity at the end of the first step with an increase of the base of support.

CONCLUSION: Despite low coefficients of correlation between the backward shift of the CoP and the horizontal acceleration of the CoM, our results suggested that an increase of the base of support by moving backward the CoP quickly after the start signal increase the horizontal acceleration of the CoM and allow to reach a better performance on short distance runs. Nevertheless, others biomechanical parameters such as mechanical power and duration of start phases should also have an impact and must be assessed in a further study.

REFERENCES:

Bezodis N.E., Trewartha G, S. A. (2008). Understand elite sprint start performance through an analysis of joint kinematics. In ISBS Conference (Ed.), *Understand elite sprint start performance through an analysis of joint kinematics* (pp. 498–501). Seoul, Korea.

Breniere, Y., & Do, M. C. (1986). When and how does steady state gait movement induced from upright posture begin? *Journal of Biomechanics*, *19*, 1035–1040.

Brenière, Y., Do, M. C., & Bouisset, S. (1987). Are dynamic phenomena prior to stepping essential to walking? *Journal of Motor Behavior*, *19*, 62–76.

Couillandre, A., Brenière, Y., & Maton, B. (2000). Is human gait initiation program affected by a reduction of the postural basis? *Neuroscience Letters*, *285*, 150–154.

Do, M. C., Breniere, Y., & Brenguier, P. (1982). A biomechanical study of balance recovery during the fall forward. *Journal of Biomechanics*, *15*, 933–939.

Frost, D. M., & Cronin, J. B. (2011). Stepping Back to Improve Sprint Performance: A Kinetic Analysis of the First Step Forwards. *Journal of Strength and Conditioning Research*.

Kraan, G. A., Van Veen, J., Snijders, C. J., & Storm, J. (2001). Starting from standing; Why step backwards? *Journal of Biomechanics*, *34*, 211–215.

Morin, J. B., Edouard, P., & Samozino, P. (2011). Technical ability of force application as a determinant factor of sprint performance. *Medicine & Science in Sports & Exercise*.

Nagahara, R., Matsubayashi, T., Matsuo, A., & Zushi, K. (2014). Kinematics of transition during human accelerated sprinting. *Biology Open*, 1–11.

Natta, F., & Breniere, Y. (1997). Effets de la posture initiale dans le départ du sprint chez les athlètes féminines de haut niveau. *Science & Sports*, *199*(12), 27s.

Termoz, N., Martin, L., & Prince, F. (2004). Assessment of postural response after a self-initiated perturbation. *Motor Control*, *8*(1), 51–63.

Winter, D.A. (1995). Human balance and posture control during standing and walking. *Gait and Posture*, *3*, 193-214.