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Acceleration capability in elite sprinters and ground impulse: Push more, brake less?

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ABSTRACT

Overground sprint studies have shown the importance of net horizontal ground reaction force impulse (IMP_H) for acceleration performance, but only investigated one or two steps over the acceleration phase, and not in elite sprinters. The main aim of this study was to distinguish between propulsive (IMP_H+) and braking (IMP_H-) components of the IMP_H and seek whether, for an expected higher IMP_H, faster elite sprinters produce greater IMP_H+, smaller IMP_H-, or both.

Nine high-level sprinters (100-m best times range: 9.95–10.60 s) performed 7 sprints (2 × 10 m, 2 × 15 m, 20 m, 30 m and 40 m) during which ground reaction force was measured by a 6.60 m force platform system. By placing the starting-blocks further from the force plates at each trial, and pooling the data, we could assess the mechanics of an entire "virtual" 40-m acceleration.

IMP_H and IMP_H+ were significantly correlated with 40-m mean speed (r=0.868 and 0.802, respectively; $P<0.01$), whereas vertical impulse and IMP_H- were not. Multiple regression analyses confirmed the significantly higher importance of IMP_H+ for sprint acceleration performance. Similar results were obtained when considering these mechanical data averaged over the first half of the sprint, but not over the second half. In conclusion, faster sprinters were those who produced the highest amounts of horizontal net impulse per unit body mass, and those who "pushed more" (higher IMP_H+), but not necessarily those who also "braked less" (lower IMP_H-) in the horizontal direction.

1. Introduction

Accelerating ones own body mass is a key determinant of performance in many sports such as soccer or rugby, but first and foremost in the sprint events. In the 100-m dash, the full acceleration phase (i.e. from the start to the maximal running velocity reached after about 40–70 m) has been shown to be directly related to performance (Delecluse, 1997; Delecluse et al., 1995; Mero, 1988; Mero et al., 1992). Basic laws of dynamics and experimental data explain that acceleration in the forward direction is related to the amount of net horizontal force and impulse produced and applied onto the ground, which will be returned through the ground reaction force (GRF) impulse, thereafter referred to as impulse (Hunter et al., 2005; Kawamori et al., 2012; Mero, 1988).

In the sagittal plane of motion, vertical (F_V) and horizontal (F_H) components of the resultant GRF, and the corresponding impulses (IMP_V and IMP_H, respectively) are the main determinants of the running motion and center of mass displacement. However, although F_V production has been related to the ability to achieve high maximal running speeds in humans (Weyand et al., 2010, 2000), F_H and the associated forward orientation of resultant GRF vector have recently been clearly put forward as a major determinant of acceleration and 100-m performance (Kugler and Janshen, 2010; Morin et al., 2011; Rabita et al. in press). Furthermore, previously mentioned studies found that vertical impulse was either very poorly (Hunter et al., 2005) or not significantly correlated (Kawamori et al., 2012) with acceleration performance.

Since a typical running support phase may be divided into a braking phase (backward orientation of the F_H vector; braking

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impulse IMP_H-) and a propulsive phase (forward orientation of the F_H vector; propulsive impulse IMP_H+), the net horizontal impulse IMP_H is the sum of IMP_H- and IMP_H+. Consequently, a given amount of IMP_H could result from many combinations of IMP_H- and IMP_H+ values. Therefore, in practical terms, to accelerate well (i.e. produce a high IMP_H), a sprinter could push more (i.e. increase IMP_H+) and/or brake less (i.e. decrease IMP_H-), and the sprint training process could be related to these possibilities. In addition, previous studies on accelerated walking in humans (Orendurff et al., 2008; Peterson et al., 2011) and accelerated locomotion in animals (McGowan et al., 2005; Roberts and Scales, 2002; Walter and Carrier, 2009) have shown that forward acceleration of the body could be achieved by modulating IMP_H- and IMP_H+, provided that IMP_H increased.

In the area of sprint running performance, it is interesting to note that few studies have specifically addressed the issue of the relative importance of IMP_H and its braking and propulsive components for acceleration performance. Hunter et al. (2005) measured GRF impulses for one single step at the 16-m mark of a typical 25-m sprint in 36 non-specialist athletes. These authors showed that relative (i.e. normalized to body mass) IMP_H and IMP_H+ were the strongest predictors of sprint velocity. Using simple linear regression, IMP_H- was not related to sprint velocity ($r^2=0.04$). When entering both IMP_H- and IMP_H+ in a multiple regression model, these two variables explained significant parts of the variance in running velocity: 7% and 57%, respectively. These authors highlighted the importance of the multiple regression approach to test the relationship between acceleration performance and both IMP_H- and IMP_H+, independently from one another. Furthermore, they commented on the fact that although relative IMP_H- accounted for a small proportion (7%) of the variance in sprint velocity, further studies were needed to find out whether "*faster athletes actually minimized their magnitude of braking*". Using a very similar protocol (30 team sport players performed 10-m sprints, and impulses were computed from GRF recorded over one single step for the first contact, and the contact at 8 m after the start), Kawamori et al. (2012) showed that relative IMP_H and IMP_H+ measured at 8 m were significantly correlated with 10-m time, but relative IMP_V and IMP_H- were not. The authors therefore discussed the "*lack of evidence that smaller braking impulse was associated with better sprint acceleration performance*". Finally, Mero (1988) studied the first contact following the starting-blocks push-off in 4 sprinters and showed that IMP_V was not significantly correlated to running velocity, whereas IMP_H+ was. However, they did not detail the correlations with IMP_H and IMP_H-.

The main limitation of these studies is that impulses were only measured for one to five steps over an entire acceleration, and/or included non-specialist sprinters of heterogeneous levels of performance, and/or data of IMP_H+ and IMP_H- were not analyzed using a multiple regression model. This statistical approach makes possible to investigate the complementary effects of several independent variables together. In the present study, we had the unique opportunity to measure GRF impulses for almost all steps of 40-m sprints in elite and sub-elite sprinters, and thus to experimentally address the question of whether elite sprint acceleration performance depends on "pushing more" and/or on "braking less" in the horizontal direction.

The first aim of this study was to investigate the relationships between GRF impulses produced over a 40-m sprint and overall acceleration performance in elite sprinters. Our hypothesis was that relative IMP_V would not be significantly correlated with performance, but relative IMP_H would. The second aim was to investigate the independent relative importance of horizontal braking and propulsive impulses.

2. Methods

2.1. Subjects and experimental protocol

Nine male elite (international level) or sub-elite (French national level) sprinters (mean ± SD: age = 23.9 ± 3.4 years; body mass = 76.4 ± 7.1 kg; height = 1.82 ± 0.07 m) gave their written informed consent to participate in this study, conducted according to the declaration of Helsinki II, and approved by the local ethical committee. Their personal 100-m best times at the moment of the study were 10.37 ± 0.27 s (range: 9.95–10.60 s).

The sprinters were tested on the indoor track of the French Institute of Sport (INSEP) during a standard sprint training session. After a 45 min warm-up managed by their personal coach, the athletes performed 7 sprints: 2 × 10 m, 2 × 15 m, 20 m, 30 m and 40 m with 4 min rest between each trial. During these sprints, vertical, horizontal and mediolateral components of the GRF were measured by a 6.60 m force platform system (natural frequency ≥ 500 Hz). This system consisted of 6 individual force plates (1.2 × 0.6 m, 5 length-wise and 1 sideways) connected in series, and covered with a tartan mat leveled with the stadium track and invisible to the runners while sprinting. Each force plate was equipped with piezoelectric sensors (KI 9067; Kistler, Winterthur, Switzerland). Instantaneous GRF signals were digitized at a sampling rate of 1000 Hz.

The protocol was designed in order to virtually aggregate the characteristics of a single complete 40-m sprint for each athlete. To do so, the starting blocks, initially placed over the first platform for the 10 m sprints were progressively placed further from the force plates for the subsequent trials (15–40 m) so that in total 17 different steps (18 foot contacts) from the block to the 40 m line could be measured. Indeed, the measurement zone allowed GRF recordings of 5 successive foot contacts for the 10 m trials (including the blocks pushing phase), 4 contacts for the 15 m trials, and 3 contacts for the 3 other trials (20, 30 and 40 m). Before pooling the data, we checked the repeatability of performance and kinematic data measured over the starting phase of the seven sprints. Indeed, after approximately 8 m of sprinting (i.e. at the 6th step) a strong repeatability was reported for several variables such as performance, step length or contact times. Therefore, all bouts were performed with the same maximal involvement of the subjects in the starting phase of the run (whatever the total distance to achieve) confirming all data could be pooled to study the mechanics of a "virtual" 40-m acceleration. For full details on this experimental design and its validity, see Rabita et al. (in press).

2.2. Mechanical variables

Force platform signals were low-passed filtered (200 Hz cutoff, 3rd order zero-phase Butterworth). Then, instantaneous data of vertical and horizontal GRF (see Fig. 1 in Rabita et al., in press) were averaged for each contact phase (10 N threshold), and expressed in both N and N\kg of body mass (N kg^{-1}). In the sagittal plane of motion, horizontal and vertical GRF impulses were computed for each support phase by integrating the values of GRF over each contact time as follows (note that IMP_V was computed by subtracting the impulse due to body weight):

$$IMP_V = \int_0^t (F_V - m.g)\,dt \tag{1}$$

$$IMP_H = \int_0^t F_H\,dt \tag{2}$$

In addition, distinction was made between the horizontal braking (IMP_H-) and propulsive (IMP_H+) impulses, defined by negative and positive values of F_H, respectively, and integrated over the corresponding periods. Data were then averaged through three phases: starting-block push-off, entire 40-m sprint, first half of the acceleration (0–20 m section, starting-block push included) and second half of the acceleration (20–40 m section). This 20-m split was chosen in accordance with the "breakpoint" phenomenon presented in detail by Nagahara et al. (2014), who showed that a breakpoint in sprint acceleration kinematics occurred around the 20-m mark.

Impulse data were expressed in N s, and then normalized to body mass (thus expressed in m s^{-1}), in order to reflect the changes in velocity of the subjects' center of mass (Hunter et al., 2005; Kawamori et al., 2012).

2.3. Performance variables

Standard photoelectric cells (Brower timing system, Draper, USA) were used to measure 40-m sprint times, and compute 40-m mean velocity (V_{40}, expressed in m s^{-1}). The photocells chronometer was triggered by the loss of contact between subjects' hand and the pressure sensor placed on the ground at the starting line.

2.4. Data analysis and statistics

Descriptive statistics are presented as mean values ± SD. Normal distribution of the data was checked by the Shapiro–Wilk normality test. Pearson's correlations were used to test the relationship between mechanical variables and performance. The

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