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Starting from standing; why step backwards?

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Abstract

At push-off, the mass centre of gravity of the body must be positioned in front of the foot to prevent a somersault. When starting a sprint from out the standing position the use of a step backwards is necessary for maximal acceleration. The aim of the present study was to quantify the positive contribution to push off from a backward step of the leg, which seems to be counterproductive. Ten subjects were instructed to sprint start in three different ways: (a) starting from the standing position just in front of the force platform on the subject's own initiative, (b) starting from the standing position on the force platform with no step backward allowed, and (c) starting out of the starting position with one leg in front of the force platform and the push-off leg on the force platform. A step backwards was observed in 95% of the starts from the standing position. The push-off force was highest in starting type (a), which had the shortest time to build up the push-off force. The results indicate a positive contribution to the force and power from a step backwards. We advocate developing a training program with special attention to the phenomenon step backwards.

Keywords: Sprint; Start; Training; Impact; Acceleration

1. Introduction

In most types of sport the human body must be accelerated from a stationary position to maximal speed. In athletics, the so-called superstart is achieved with the use of blocks. In literature, the position of the blocks, the anteroposterior inter-block spacing (Harland, 1997), and the angular relations between the body parts are varied to define optimal starting conditions (Henry, 1952; Baumann, 1976, 1979; Hoster, 1979; Mann, 1981; Mero, 1983; Korchemny, 1992; Mendoza, 1993; Plamandon, 1984).

Optimisation of the start can also be achieved by the sequence of muscle activation. In professional sprinters intermuscular co-ordination is described, which manifests itself in sequencing activation of hip, knee and ankle muscles (van Ingen Schenau and Bobbert, 1988; Jacobs and van Ingen Schenau, 1992).

However, none of these studies has investigated starting without blocks; therefore, results from these latter studies on athletics can not be extrapolated to other sports. In starting from the standing position it is noteworthy that first the push-off leg is placed backwards. There are no reports describing this phenomenon, or quantification of its effect on performance. Therefore, we studied different possibilities of starting from the standing position. Aim of the study was to investigate why the push-off leg is placed backwards, i.e. to determine the mechanical advantage.

2. Materials and methods

We verified the positive effects of the paradoxical step backwards by:

(a) comparing ankle and hip start, with push-off force in three directions (Fig. 1), delay time, i.e. the difference between the reaction time of the person, and the begin time, i.e. the beginning of building up force. Begin time is the initiation of building up force and is defined when force in forward direction is raised above 10 N (Fig. 4). *End time is defined by leaving the force plate. When force in forward direction is decreased under 10 N end time is defined.*

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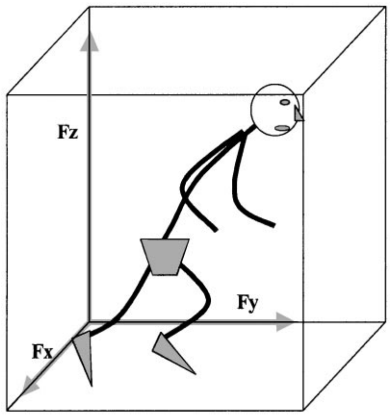

Fig. 1. The force platform registers three components of the foot-ground contact force. F_y, the horizontal component, in the direction of sprinting, F_z, the vertical component, and F_x, the horizontal component of the foot-ground contact force, perpendicular to the direction of sprinting.

(b) assessment of the body impulse by comparing the impulse out of the starting position with that out of the standing position.
(c) assessment of the optimal starting position by measuring force, begin time and impulse time.
(d) comparing the power in the three starting types in one trial of one person. Power is computed by

$$P = \frac{Fs}{\Delta t},$$

F is the force, s is the displacement of the mass centre of gravity and Δt is the time force is performed.

Ten healthy young males were selected in whom a sprint start from out of the standing position is an important part of their sports; it was required that these persons trained at least 2 times a week. The group was aged 19–25 years; body mass 65–98 (77.6 $\pm$ 11.3) kg.

The subjects were filmed with a 50 Hz camera in the sagittal and frontal planes as they started to run at maximal speed.

To determine the external ground forces on the body, a Kistler force platform was used to record the vertical and horizontal components with a *bit resolution* of 4096 bits and a sample frequency of 200 Hz. A light was flashed at the *sprint start* to allow synchronisation of cameras with the force platform.

Three types of starting positions were performed:

(a) Three starts out of standing position just in front of the force platform on the subject's own initiative
(b) Three starts out of standing position on the force platform with no step backwards allowed
(c) Three starts in a starting position with one leg in front of the force platform and the push-off leg on the force platform.

At least three trials were allowed before each type of start was performed. After the nine starts (a)–(c) were completed, the subjects were instructed to do each type of sprint once again at random. Then, only the starts according to (a), with the paradoxical step backwards were analysed. In the starts according to (b), any attempt which included a step backwards was excluded, and another start had to be performed. Force plate recordings were sampled with Matlab 5.1. *The averages of four trials of force, begin time, impulse time were considered the dependent variables, analysed using ANOVA (analysis of variance) with subjects and different sprint type as explanation factors*. In respect to the high forces the force plate was calibrated in three directions, every day. After all, there were not any remarkable drifts in the results.

3. Results

The first phase of forward acceleration of the mass centre of gravity of the body must be produced by the horizontal component of the foot-ground contact force (F_y) which is raised by forward tilting of the trunk about the ankle axes. Then, two options are observed:

First (Fig. 2), this tilting can be continued, while the knees bend and push off follows such that the foot force points at the mass centre of gravity of the body to prevent a somersault; knee extension produces the acceleration force (F_y).

The second option begins in the same manner, i.e. with forward tilt of the body about the ankle axes (Fig. 3a). Then, however, the body is rotated about the mass centre of gravity of the body, which goes with a backward sway of one leg and a forward sway of the other (Fig. 3b). The backward sway is called paradoxical, because it seems counterproductive to forward movement. This phase is followed by foot-ground contact (Fig. 3c) and stretching of the push-off leg (Fig. 3d). Then, instead of moving the mass centre of gravity of the body in front of the push-off leg, the paradoxical step backwards moves the point of impact behind the mass centre of gravity of the body (sb in Fig. 3c).

The leg, which is moved backwards, becomes the push-off leg and generates two types of impulses: the impulse by breaking the backward fall of the total body, *body impulse*; and the impulse by leg extension, *leg impulse*.

Nine sprinters initiated their four starts out of the standing position with the paradoxical step backwards. In two trials, however, one person first did a step forward followed by a backward step of the contralateral leg with its point of impact on the ground behind the first step. Which means 95% of the trials initiated with a step backwards. All the sprinters indicated problems with type (b) sprint, because they had to suppress the step backwards; many attempts had a step backwards in spite of the effort to avoid this. The starts according to (c) showed interindividual differences in the movement pattern. The push-off leg was behind and 7 persons initiated with lifting the other leg forward while pushing with the posterior leg. Others lifted their posterior leg, tilted the body around the ankle of the anterior leg with which push off was accomplished. Two trials by two different persons had a step backwards with the anterior positioned leg followed by a contribution to push off. Only one person had a higher force when starting according to (c). In this subject, the lowest force was produced when starting according to (b).

Only one person had a shorter impulse time when starting according to (c). All the starts according to (b) required a longer time on the force platform till push-off.

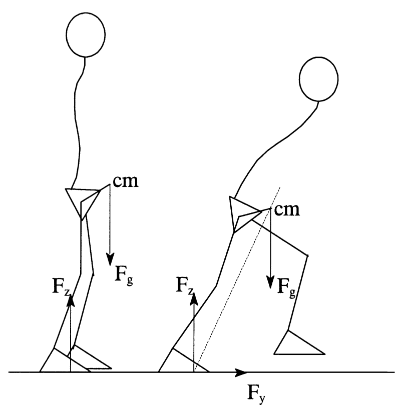

Fig. 2. After forward tilting of the trunk about the ankle axes foot force (F_y) is generated, which accelerates the mass centre of gravity. Cm is the mass centre of gravity. F_g the gravitationforce. F_z the vertical component of the foot-ground contact force. F_y the horizontal component of the foot-ground contact force in the direction of sprinting.

Table 1 gives average values for the different parameters with the standard deviation (SD) and the standard error (SE).

Concerning the force in forward direction:

- sprint type (a) is significantly higher than sprint types (b) and (c), with $p < 0.0005$
- sprint type (b) is significantly lower than sprint types (a) and (c), with $p < 0.0005$

Concerning the begin time:

- sprint type (a) is significantly higher than sprint types (b) and (c), with $p < 0.0005$
- sprint type (c) is significantly lower than sprint types (a) and (b), with $p < 0.0005$

Concerning the impulse time:

- sprint type (a) is significantly lower than sprint types (b) and (c), with $p < 0.0005$
- sprint type (b) is significantly higher than sprint types (a) and (c), with $p < 0.0005$

Figs. 4–6 show the relations between force (F_y), impulse (I_y), acceleration (a_y), velocity (v_y) and displacement (s_y) for the three types of starting. Fig. 4 shows the different variables according to starting type (a). At $t = 0$ the light is flashed and the registration begins. The first vertical line indicates the reaction time until lift off. The begin time is the initial contact on the force plate. The mean force in Fig. 4 during the impulse time is 542 N. The displacement (s_y) and the velocity (v_y) of the mass centre of gravity of the body at the end time ($t = 0.735$ s) are 0.214 m and 1.86 m s^{-1}, respectively.

Fig. 5 shows the different variables according to starting type (b). The end time is 1.335 s and the begin time is 0.28 s. The impulse time, time of force on the platform, is increased according to type (a) from 0.220 s to 1.055 s.

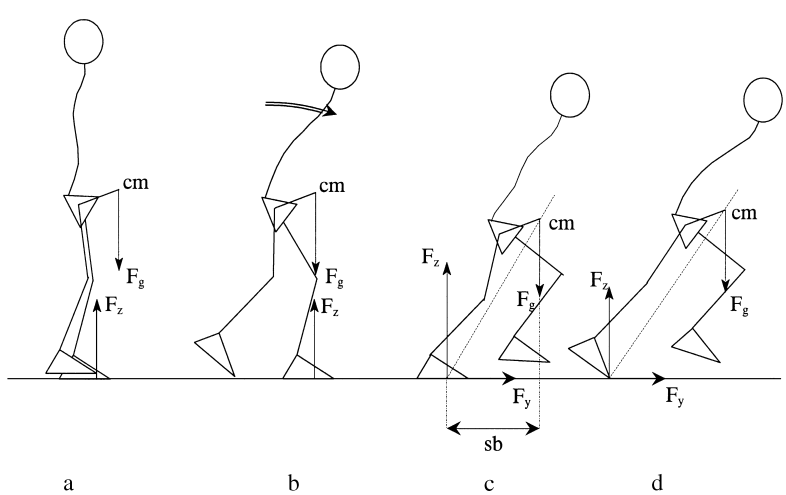

Fig. 3. Starting with a step backwards: (a) body tilt about the ankle axes; (b) body rotation round the mass centre of gravity of the body; (c) foot-ground contact; (d) extension of leg and trunk. Cm is the mass centre of gravity. F_g is the gravitationforce. F_z is vertical component of the foot-ground contact force. F_y is horizontal component of the foot-ground contact force. Sb is distance between the point of impact and the mass centre of gravity.

Table 1
Average values of all tests of the mean force, F_y, begin time and the impuls time of the three starting types. Types of start (a), (b) and (c) see text for explanation

	F_{ya} (N)	F_{yb} (N)	F_{yc} (N)	Begin time start (a) (s)	Begin time start (b) (s)	Begin time start (c) (s)	Impulse time start (a) (s)	Impulse time start (b) (s)	Impulse time start (c) (s)
	537.4	264.7	409.3	0.460	0.304	0.211	0.268	0.776	0.395
SD	104.1	55.1	75.4	0.076	0.121	0.098	0.052	0.201	0.054
SE	17.0	17.0	17.0	0.025	0.025	0.025	0.037	0.037	0.037

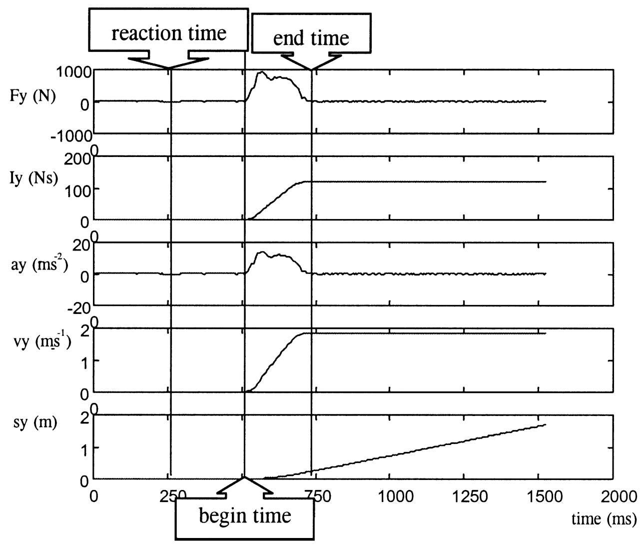

Fig. 4. Force (F_y), Impulse (I_y), acceleration (a_y), velocity (v_y) and displacement (s_y) — time history in the y-direction. Starting on own initiative (with a step backwards).

The mean force (F_y) during the whole period is 174 N. At the end time of starting type (a) the displacement and the velocity of the mass centre of gravity of the body according to start type (b) are 0.129 m and 0.33 m s^{-1}, respectively.

Starting according to type (a) gives a fourfold higher power.

P_a is the power according to type (a), so

$$P_a = \frac{\bar{F}_y s}{\Delta t} = \frac{530 \times 0.214}{0.22} \approx 515\,\text{W},$$

P_b is the power according to type (b), so

$$P_b = \frac{\bar{F}_y s}{\Delta t} = \frac{174 \times 0.786}{1.055} \approx 130\,\text{W}.$$

Fig. 6 shows starting according to type (c). Reaction time is the same as begin time. The displacement and the velocity at the end time ($t = 0.595$ s) are 0.428 m and 2.27 m s^{-1}, respectively. The mean force (F_y) during the

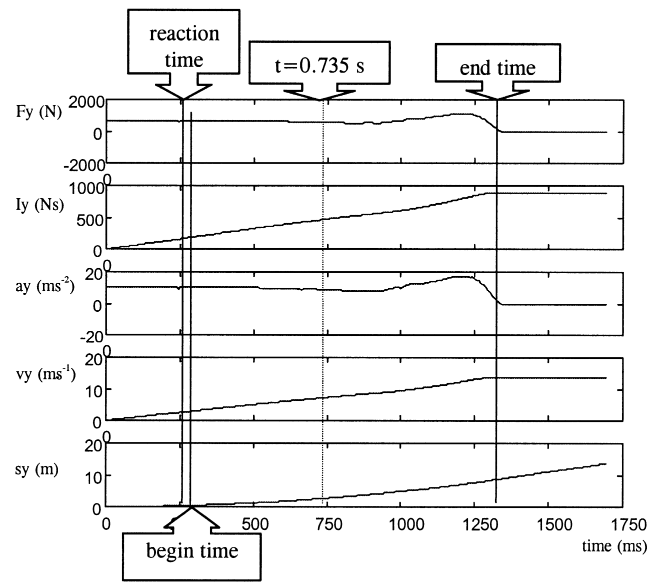

Fig. 5. Force (F_y), Impulse (I_y), acceleration (a_y), velocity (v_y) and displacement (s_y) — time history in the y-direction. Starting with no step backwards allowed.

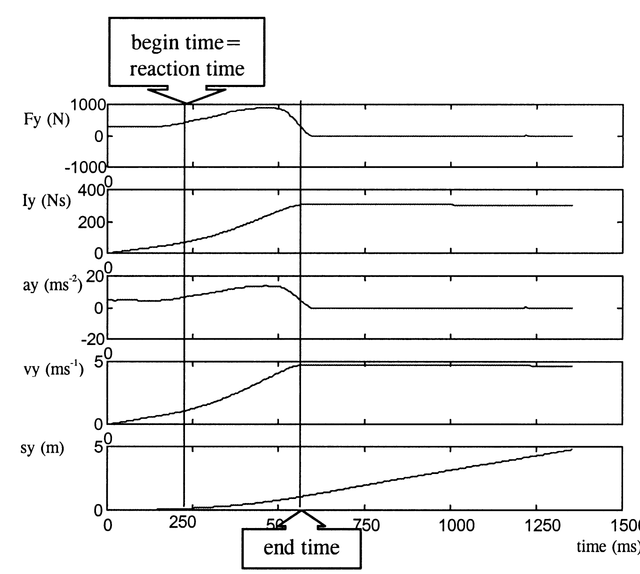

Fig. 6. Force (F_y), Impulse (I_y), acceleration (a_y), velocity (v_y) and displacement (s_y) — time history in the y-direction. Starting with one leg posterior to the other.

whole period is 354 N. Compared to (a) the impulse time is longer, the displacement is larger and the mean force smaller, so the power of starting type (c) is

$$P_c = \frac{\bar{F}_y s}{\Delta t} = \frac{354 \times 0.428}{0.36} \approx 420\,\mathrm{W}$$

4. Discussion

Forward acceleration is maximal when an athlete starts in stooped position with the use of blocks. In many sports, e.g. soccer, hockey, tennis and basketball, a sudden change of position requires a start out of the upright standing position. We found it noteworthy that this is always accompanied by a step backwards. Such movement seems counterproductive with regard to acceleration in the opposite, forward direction. This study showed that starting with the paradoxical step backwards results in higher force and higher power during foot contact compared with the start without a paradoxical step backwards. This positive contribution to the start originates from the impulse at foot impact resulting from the kinetic energy of the leg in the step backwards. Our measurements in the standing start explain the automatic reaction of the human body to perform the fastest acceleration. All subjects in our experiments had such a reaction and had difficulty to perform the test in another way.

The step backwards seems to be counterproductive because of a delay in which force can be built-up. But the shorter time to building up force and the higher force are more important in sprint start out of the standing position.

An optimal start from an upright standing position is not part of training programs, but follows an individual pattern as developed by experience.

We advocate developing a training program which, based on our results, should be based on maximisation of foot impact when making a step backwards. We propose to also utilise the build-up of impulse when starting from the blocks.

5. Conclusions

The results of this study allow to conclude that:

- The fastest start from the upright position requires a point of impact on the ground which is behind the mass centre of gravity of the body.
- From the standing position the fastest start is achieved with a paradoxical step backwards.
- The step backwards gives higher force and higher power during foot contact compared with the start without a paradoxical step backwards and compared with a start with one leg infront of the other which is used as push-off leg.
- The start with a step backwards needs a shorter time to build up the push-off force and peak force is higher, thus acceleration increases.
- A training program should be developed for the standing start which maximises impulse.

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