This is the published version of a paper published in *Journal of Sports Sciences*.

Citation for the original published paper (version of record):

The effect of a reduced first step width on starting block and first stance power and impulses during an athletic sprint start.
*Journal of Sports Sciences*, 37(9): 1046-1054
https://doi.org/10.1080/02640414.2018.1541161

Access to the published version may require subscription.

N.B. When citing this work, cite the original published paper.

This is an Open Access article distributed under the terms of the Creative Commons Attribution-NonCommercial-NoDerivatives License (http://creativecommons.org/licenses/by-nc-nd/4.0/), which permits non-commercial re-use, distribution, and reproduction in any medium, provided the original work is properly cited, and is not altered, transformed, or built upon in any way.

Permanent link to this version:
http://urn.kb.se/resolve?urn=urn:nbn:se:gh:diva-5479
The effect of a reduced first step width on starting block and first stance power and impulses during an athletic sprint start

Paul Sandamas, Elena M. Gutierrez-Farewik & Anton Arndt

To cite this article: Paul Sandamas, Elena M. Gutierrez-Farewik & Anton Arndt (2018): The effect of a reduced first step width on starting block and first stance power and impulses during an athletic sprint start, Journal of Sports Sciences, DOI: 10.1080/02640414.2018.1541161

To link to this article: https://doi.org/10.1080/02640414.2018.1541161

© 2018 The Author(s). Published by Informa UK Limited, trading as Taylor & Francis Group.

Published online: 21 Nov 2018.

Submit your article to this journal

Article views: 60

View Crossmark data
The effect of a reduced first step width on starting block and first stance power and impulses during an athletic sprint start

Paul Sandamas, Elena M. Gutierrez-Farewik and Anton Arndt

ABSTRACT
This study investigated how manipulating first step width affects 3D external force production, centre of mass (CoM) motion and performance in athletic sprinting. Eight male and 2 female competitive sprinters (100m PB: 11.03 ± 0.36 s male and 11.6 ± 0.45 s female) performed 10 maximal effort block starts. External force and three-dimensional kinematics were recorded in both the block and first stance phases. Five trials were performed with the athletes performing their preferred technique (Skating) and five trials with the athletes running inside a 0.3 m lane (Narrow). By reducing step width from a mean of 0.31 ± 0.06 m (Skating) to 0.19 ± 0.03 m (Narrow), reductions were found between the two styles in medial block and medial 1st stance impulses, 1st stance anterior toe-off velocity and mediolateral motion of the CoM. No differences were found in block time, step length, stance time, average net resultant force vector, net anteroposterior impulse nor normalised external power. Step width correlated positively with medial impulse but not with braking nor net anteroposterior impulse. Despite less mediolaterally directed forces and less mediolateral motion of the CoM in the Narrow trials, no immediate improvement to performance was found by restricting step width.

Introduction
The ability to accelerate from a stationary starting position is an important performance aspect for many sports. In sprinting, performance at the start of a race has a major effect on finishing time (Milan Čoh, Tomažin, & Štuhec, 2006). Even a small difference in techniques used during the acceleration phase can have a major influence on performance (Babić, Čoh, & Dizdar, 2011; Bezodis, Salo, & Trewartha, 2014).

There are several important parameters characterising sprint start performance. Examples of these include block exit velocity, peak block phase acceleration or time to a certain distance, e.g. 5 m or 10 m. In a comparison of 10 such performance measures, Bezodis, Salo, and Trewartha (2010) reported that normalised average horizontal power ($P_{\text{NAA}}$) gave the best measure of sprint start performance on the basis that it not only takes morphology and change in velocity (in the form of change in kinetic energy) into consideration but also the duration of the push against the ground. Average power can therefore be enhanced by increasing block exit velocity and/or decreasing block time. Normalised average horizontal power has recently been reported in sprint start literature as a measure of performance for both block and 1st stance phases (Willwacher, Feldker, Zohren, Herrmann, & Brüggemann, 2013; Willwacher et al., 2016).

For a multibody system such as the human body, the sum of internal forces is zero, and the acceleration of the whole body centre of mass (CoM) during the block start and contact phases is directly related to the resultant of the externally applied forces (Winter, 2005). As such, the generation of maximum anterior force has been advocated for sprint performance (Harland & Steele, 1997). According to the impulse-momentum relationship, impulses can be used to give a measure of the change in velocity of the CoM during the ground contact phase (Hunter, Marshall, & McNair, 2004). Although the mediolateral impulse is the smallest of the three orthogonal block impulses (Otsuka et al., 2014; Rabita et al., 2015) the fact that it is non-zero suggests it could have an effect on CoM motion and step width.

The greatest step width during elite level sprinting occurs during the first few ground contact phases (Ito, Ishikawa, Isolehto, & Komi, 2006) and those wide steps involve hip motion in all three planes (Debaere, Delecluse, Aerenhouts, Hagman, & Jonkers, 2013). As the sprinter progresses into a more upright posture, step width reduces and becomes consistent for the remainder of the race (Nagahara, Mizutani, Matsuo, Kanehisa, & Fukunaga, 2017). The legs’ flailing action during the first few steps with pronounced motion outside the sagittal plane resembles a technique seen during the acceleration phase in ice skating, and henceforth will be referred to as “skating style”.

In running, a greater step width is associated with a larger mediolateral component of the GRF (McCly & Cavanagh, 1994). The wider steps seen at the start of a race can thus be expected to have a larger component of their GRF pointing in the mediolateral direction than the later steps. Practically speaking, it seems unlikely that large mediolateral forces would be beneficial to sprint performance. Despite this possible detrimental contribution to performance, step width has received limited attention in the literature. In the study of external
forces during a sprint start, Otsuka et al. (2014) found no significant differences in step width or mediolateral impulses between well-trained, trained and non-trained athletes during the block and subsequent first two steps. However, the transverse plane projection of the GRF, which is composed of the anteroposterior and mediolateral components of the average GRF vector was found to point more anteriorly for the well trained sprinters compared to the other two groups. On the other hand, based on their descriptive study of internationally competing sprinters, Ito et al. (2006) recommended that wide steps be used at the start of the race as a means to develop driving force, but this mechanism was not described in detail. Further research is required to help shed light on this apparent contradiction.

Although GRFs in sprinting have been extensively studied, most studies have focused on the sagittal plane. To the best of the authors' knowledge, the effect of manipulating 1st step width on 3D block impulses and GRFs in sprinting has not been studied. The primary aim of this study is thus to investigate how athletes' natural skating style block and ground reaction forces are affected when the 1st step width is restricted. The first hypothesis was that by reducing step width, a reduction in block and 1st stance mediolateral impulses will be found. If the first hypothesis was true then it would suggest that the average transverse plane force vector is likely to point more in the anterior direction, and so the second hypothesis was that by reducing step width, an increase in block and 1st stance net anteroposterior impulses would be found.

Methods

Participants

Ten competitive sprinters (8 male and 2 female) (mean ± SD: age, 23 ± 6 years, height 1.77 ± 0.10 m, mass 72.7 ± 13.6 kg, personal best: men 11.03 ± 0.36 s, women 11.6 ± 0.45 s) participated in the study. The participants included indoor World and European Championships 60 m finalists. Written informed consent was obtained from the athletes and the study was approved by the Stockholm Regional Ethical Committee.

Procedures

Testing took place indoors in a laboratory fitted with a 1.22 m wide tartan running surface. The running track was 15 m long, fitted with a crash mat on the end wall. To ensure the athletes were not affected by the restricted laboratory track length, pilot testing was performed on a full size indoor running track, as follows: the vertical position of a marker placed on the processus spinosus of the C7 of the athletes’ at 2nd stance toe-on was compared for track and laboratory running. Using the Wilcoxon Signed Rank test, no significant differences were observed. We thus assume that the laboratory setting was adequate for testing the hypothesis of this study.

After an individualised warm-up, each sprinter performed 10 maximum effort block starts. Five trials were performed with the athlete performing his/her natural technique (Skating) and five trials were performed with the athlete running inside a 0.3 m lane (Narrow), which corresponds to the width between starting blocks. The narrow lane was constructed by laying two parallel ropes on the track surface. The ends of each rope were attached to the outside edges of the starting blocks and terminated at the crash mat. The athletes were given as many trials as they thought necessary to familiarise themselves with the demands of a narrow start.

The starting commands were similar to those in competition, with the exception that a loud hand clap was used instead of a starting pistol. 3D kinematic data and external forces were collected from the initiation of the starting command to the mid-flight phase following the first step contact phase. The athletes decides how much recovery time they needed between trials (approximately five minutes)

Kinematic data were recorded with a 12-camera (Oqus 4, Qualisys AB, Göteborg, Sweden) motion analysis system at a sampling frequency of 250 Hz. A full-body marker protocol consisting of 78 retroreflective markers was used, including eight technical clusters strapped to the upper arm, forearm and shank (Figure 1). The technical clusters were used for greater robustness of segment tracking.

First step GRFs were recorded using a 0.6 m × 0.4 m force plate (Kistler 9281EA, AG Winterthur, Switzerland) at a sampling frequency of 1500 Hz. The force plate was covered with the tartan surface, which was fitted to be flush with the running surface. The athletes ran in their own spiked shoes.

Reaction force data were also collected at 1500 Hz from each starting block by fitting a custom made plate containing
a 3D force transducer (Kistler 9347B) to the surface of each foot plate. The athletes were allowed to adjust the starting blocks to their own preferred block spacing and block obliquity (mean (SD) leading and trail leg block angles with respect to the horizontal, were 51.3 (5.3)° and 54.4 (4.5)°, respectively). The athletes used the same block spacing and block obliquity for the skating and narrow trials. The block reaction forces and GRFs were collected simultaneously with the kinematic data in Qualisys Track Manager (QTM, Qualisys AB, v.2.14).

**Data processing**

A 3D full-body model with 17 segments (head, trunk, pelvis, upper arms lower arms, hands, thighs, shanks and feet) was created (Visual 3D, C-Motion Inc, Germantown, MD, USA, v.6). The hip joint centre was defined according to Bell, Brand, and Pedersen (1989). The knee and ankle joint centres were defined as the midpoint of the femoral epicondyles and malleoli, respectively.

Since inverse dynamics were performed (separate study), the marker and force plate data were filtered (12 Hz) with a 4th-order low pass Butterworth filter in Visual 3D to prevent artefacts during ground impact (Bezodis, Salo, & Trewartha, 2013; Bisseling & Hof, 2006). The cut-off frequency was determined using residual analysis (Winter, 2005).

Step width and step length were calculated from the mediolateral and anteroposterior distances, respectively, between the midpoints of the 1st and 5th metatarsal head markers of the leading foot on the starting block to the other foot at first touchdown (Otsuka et al., 2014). Step width and step length were normalised by dividing by leg length, external forces were normalised by dividing by body weight.

The start of the block phase was defined as the first instance when the first derivative of either the front or rear block resultant force-time curve was > 500 N/s (Brazil et al., 2017). The first stance phase was defined when the vertical GRF was >10 N (Rabita et al., 2015). The CoM was automatically calculated in the Visual 3D model from the location of the CoM of the individual segments. The mass of each segment was determined from total body mass (Dempster, 1955) and the segment mass locations were determined from a mathematical model (Hanavan, 1964). The CoM velocity in all directions was calculated by computing the first derivative of its position with respect to time.

Average horizontal power ($P_{AH}$) and normalised average horizontal power ($P_{NAH}$) for both the block and 1st stance phases were computed using the equations given by Bezodis et al. (2010):

$$P_{AH} = \frac{m(v_{final}^2 - v_{initial}^2)}{2\Delta t}$$  \hspace{1cm} (1)

where $m =$ subject mass, $v_{final} =$ final velocity i.e. anteroposterior CoM velocity at end of 1st stance phase, $v_{initial} =$ CoM velocity at start of 1st contact phase, $\Delta t$ is the 1st stance contact time. Average horizontal block power ($P_{AH_B}$) was computed using Eq. 1, but using initial and final CoM velocities of the block phase (note that $v_{initial} = 0$ at start of block phase), and $\Delta t$ is the block pushing time.

The $P_{AH}$ and $P_{AH_B}$ were normalised and made dimensionless:

$$P_{NAH} = \frac{P_{AH}}{mg^{3/2} \cdot l^{1/2}}$$  \hspace{1cm} (2)

where $g$ is the gravity constant and $l$ is the leg length (vertical coordinate of the hip joint centre, computed during the standing reference trial). Normalised average horizontal block power ($P_{NAH}$) was computed similarly to Eq. 2, but with the $P_{AH_B}$ as the numerator.

In order to assess if learning effects or fatigue could have affected the results, $P_{NAH}$ was plotted as a function of trial number for each athlete. A linear trendline (Microsoft Excel, 2013) was then plotted and the gradients of each sprinter’s skating and narrow plots were compared. It was assumed that if the gradients of these trendlines were similar for each athlete then neither learning effect nor fatigue would have significantly affected the results.

The GRFs projected onto the sagittal (x-y), frontal (z-y) and transverse (x-z) planes were calculated as follows:

$$F_{GR \text{ sag}} = \tan^{-1} \left( \frac{\text{mean vertical GRF}}{\text{mean anteroposterior GRF}} \right) \cdot \frac{180°}{\pi}$$  \hspace{1cm} (3)

$$F_{GR \text{ front}} = \tan^{-1} \left( \frac{\text{mean mediolateral GRF}}{\text{mean vertical GRF}} \right) \cdot \frac{180°}{\pi}$$  \hspace{1cm} (4)

$$F_{GR \text{ trans}} = \tan^{-1} \left( \frac{\text{mean mediolateral GRF}}{\text{mean anteroposterior GRF}} \right) \cdot \frac{180°}{\pi}$$  \hspace{1cm} (5)

These represent modifications of the equations used by Otsuka et al. (2014).

Since the force data were collected at a higher frequency than the motion capture data, 1st stance impulse calculations were computed using numerical integration using custom designed scripts (Matlab R2015b, Mathworks Inc, USA). The impulses were divided by mass to give the net change in velocity during stance and, similar to Hunter, Marshall and McNair (2005) are thus relative impulses. Since it was assumed that the initial velocity of the sprinter is zero, the relative block impulses are equal to the whole body CoM block exit velocities.

An inclusion criterion for this study was that the participant’s mean 1st step width was at least 30% greater than the step width of their narrow trials. This was also used as the definition of “skating technique” for this study. The aforementioned ten sprinters matched this criterion. All participants performed five skating and five narrow trials except for two sprinters. These two athletes performed five skating and three narrow trials.

**Statistics**

The Shapiro-Wilk test was used to test the data distribution for normality (IBM SPSS 24, IBM Corp., NY, USA). Data were deemed to have a normal distribution and dependent t-tests were used to determine differences between the skating and narrow trials for step width, step length, block time, contact time and anterior velocity. Correlations between variables
were tested with either Pearson’s r (for normally-distributed data) or Spearman rho (for non-normally distributed data). Correlations were considered very high for coefficients \( r > 0.90 \), high for \( 0.70 < r \leq 0.89 \), moderate for \( 0.50 < r \leq 0.69 \), and low for \( r \leq 0.50 \) (Hinkle, Jurs, & Wiersma, 2009). Significance was considered at a \( p < 0.05 \) level. Cohen’s d (effect size) was computed for each variable as follows:

\[
\frac{\mu_{\text{Skating}} - \mu_{\text{Narrow}}}{\sigma_{\text{Skating}}}
\]

(6)

The effect size was defined as trivial (<0.20), small (0.20–0.49), medium (0.50–0.79) or large (>0.80) according to Cohen (1992).

Results

A comparison of each athlete’s linear trendlines for \( P_{\text{NAH}} \) revealed that these generally had a low gradient for all athletes with no consistent pattern for the direction of the slope between athletes or between skating and narrow trials. No athlete showed more than three consecutive trials of increasing or decreasing values. These results indicated that no significant learning or fatigue effect was present.

First step width was greater in skating than in narrow trials (Table 1). The anterior CoM velocity at 1st stance toe-off was faster for the skating than for the narrow trials (mean (SD): 4.37 (0.18) m/s and 4.32 (0.15), respectively). No differences were found between the two styles for block time, step length, contact time and CoM velocity at toe-on. No correlation between anteroposterior toe-on and toe-off velocities to step width was found (Figure 2).

In the transverse plane, in addition to forward motion, the motion of the athletes’ CoM was first lateral towards the rear leg during the block phase and then lateral towards the swing leg during the stance phase (Figure 3). More pronounced mediolateral motion can be seen for the skating trials.

Medial and vertical block impulses were higher in for the skating trials, but no difference was found in \( P_{\text{NAHB}} \). Typical examples of mediolateral block forces are shown in Figure 4.

During the skating trials the average GRF vector was found to point more towards the side of the swing leg during both the block phase and 1st stance phases (Table 2 and Figure 5). The GRF vector magnitudes are given in Table 3.

During the 1st step phase the medial and the propulsive components of the net anteroposterior impulse were higher for the skating trials but no difference was found in \( P_{\text{NAH}} \) (Table 3).

Table 1. Comparison of kinematic data: normalised step width, step length, block time, 1st stance contact time, and anteroposterior centre of mass (CoM) velocity at toe-on and toe-off for both skating and narrow trials.

<table>
<thead>
<tr>
<th></th>
<th>Skating</th>
<th>Narrow</th>
<th>Effect Size</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean</td>
<td>SD</td>
<td>mean</td>
<td>SD</td>
</tr>
<tr>
<td>Step width (front foot to 1st step)*</td>
<td>0.31</td>
<td>0.06</td>
<td>0.19</td>
<td>0.03</td>
</tr>
<tr>
<td>Step length (front foot to 1st step)</td>
<td>1.13</td>
<td>0.10</td>
<td>1.12</td>
<td>0.12</td>
</tr>
<tr>
<td>1st Stance Contact time (s)</td>
<td>0.21</td>
<td>0.01</td>
<td>0.20</td>
<td>0.01</td>
</tr>
<tr>
<td>1st Stance Ant Velocity at Toe-on (m/s)</td>
<td>3.10</td>
<td>0.16</td>
<td>3.08</td>
<td>0.16</td>
</tr>
<tr>
<td>1st Stance Ant Velocity at Toe-off (m/s)*</td>
<td>4.37</td>
<td>0.18</td>
<td>4.32</td>
<td>0.15</td>
</tr>
<tr>
<td>Block time (s)</td>
<td>0.37</td>
<td>0.03</td>
<td>0.38</td>
<td>0.03</td>
</tr>
</tbody>
</table>

The presented values are the group average values for all athletes and all trials (i.e. the mean of the mean). *Significant difference between Skating and Narrow trials (\( p < 0.05 \)).

![Figure 2](image-url) Relationship between anterior CoM velocity at 1st stance toe-off versus normalised step width. No correlation between these parameters was observed for either step width.
The mediolateral GRF peaked at approximately 0.30 and 0.16 times BW for skating and narrow trials, respectively. The vertical GRF peaked at approximately two times BW for both skating and narrow trials. Although some variation could be seen in the braking impulses, no difference was seen in the mean braking impulses for the group. The propulsive GRF peaked at approximately 1.1 times BW for both skating and narrow trials.

A high correlation was found between medial block impulses and normalised step width (Figure 6) for the skating and narrow trials, respectively. Low correlations were found between anterior block impulses and step width \((r = -0.274, p = 0.091\) skating and \(r = 0.039, p = 0.812\) narrow) or between vertical block impulses and step width \((r = -0.061, p = 0.713\) skating and \(r = -0.066, p = 0.691\) narrow). A moderate correlation was found between 1st stance mediolateral impulses and normalised step width (Figure 6). No correlations were found between normalised step width and; braking \((r = -0.240, p = 0.116\) skating and \(r = -0.062, p = 0.702\) narrow), propulsive \((r = -0.143, p = 0.356\) skating and \(r = 0.083, p = 0.606\) narrow) vertical \((r = -0.220, p = 0.151\) skating, \(r = 0.305, p = 0.053\) narrow) or the net anteroposterior impulses \((r = 0.027, p = 0.864\) skating), \(r = 0.161, p = 0.316\) narrow).

**Discussion**

The aim of this study was to investigate the influence of step width on ground reaction forces, motion of the whole body...
Table 2. Mean ground reaction force angles during the starting block and 1st step phases.

<table>
<thead>
<tr>
<th>Phase</th>
<th>GRF Angle</th>
<th>Skating mean (°)</th>
<th>SD</th>
<th>Narrow mean (°)</th>
<th>SD</th>
<th>p value</th>
<th>Effect Size (Cohen’s d)</th>
<th>Effect Size Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Starting Block</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$F_{GR ; sag}$</td>
<td>52.8</td>
<td>2.9</td>
<td></td>
<td>53.7</td>
<td>2.9</td>
<td>0.07</td>
<td>0.31</td>
<td>small</td>
</tr>
<tr>
<td>$F_{GR ; front}$</td>
<td>3.1</td>
<td>1.2</td>
<td></td>
<td>1.1</td>
<td>0.6</td>
<td>&lt;0.01</td>
<td>1.59</td>
<td>large</td>
</tr>
<tr>
<td>$F_{GR ; trans}$</td>
<td>4.8</td>
<td>3.2</td>
<td></td>
<td>1.9</td>
<td>1.9</td>
<td>&lt;0.01</td>
<td>0.88</td>
<td>large</td>
</tr>
<tr>
<td><strong>1st Step</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$F_{GR ; sag}$</td>
<td>64.0</td>
<td>1.7</td>
<td></td>
<td>64.8</td>
<td>1.1</td>
<td>0.13</td>
<td>0.49</td>
<td>small</td>
</tr>
<tr>
<td>$F_{GR ; front}$</td>
<td>6.8</td>
<td>2.2</td>
<td></td>
<td>3.5</td>
<td>1.8</td>
<td>&lt;0.01</td>
<td>1.55</td>
<td>large</td>
</tr>
<tr>
<td>$F_{GR ; trans}$</td>
<td>−9.6</td>
<td>4.6</td>
<td></td>
<td>−4.0</td>
<td>3.9</td>
<td>0.01</td>
<td>1.22</td>
<td>large</td>
</tr>
</tbody>
</table>

*Significant difference between Skating and Narrow trials (p < 0.05).

Figure 5. Visual representation of the ensemble average normalised GRF for the block phase (top row) and 1st stance phase (bottom row). *Significant difference between Skating and Narrow trials (p < 0.05).

Table 3. Starting block and 1st step: relative impulses, normalised external power and ground reaction force vector magnitudes.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Variable</th>
<th>Skating mean</th>
<th>SD</th>
<th>Narrow mean</th>
<th>SD</th>
<th>p value</th>
<th>Effect Size (Cohen’s d)</th>
<th>Effect Size Evaluation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Starting Block</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anteroposterior GRF (BW)</td>
<td>0.87</td>
<td>0.10</td>
<td></td>
<td>0.86</td>
<td>0.10</td>
<td>0.38</td>
<td>0.13</td>
<td>trivial</td>
</tr>
<tr>
<td>Mediolateral GRF (BW)*</td>
<td>0.06</td>
<td>0.02</td>
<td></td>
<td>0.02</td>
<td>0.01</td>
<td>&lt;0.01</td>
<td>1.83</td>
<td>large</td>
</tr>
<tr>
<td>Vertical GRF (BW)*</td>
<td>1.15</td>
<td>0.02</td>
<td></td>
<td>1.16</td>
<td>0.02</td>
<td>0.03</td>
<td>0.59</td>
<td>medium</td>
</tr>
<tr>
<td>Resultant GRF (BW)</td>
<td>1.44</td>
<td>0.07</td>
<td></td>
<td>1.44</td>
<td>0.07</td>
<td>0.93</td>
<td>0.01</td>
<td>trivial</td>
</tr>
<tr>
<td>Anteroposterior impulse (m/s)</td>
<td>3.21</td>
<td>0.16</td>
<td></td>
<td>3.19</td>
<td>0.16</td>
<td>0.37</td>
<td>0.12</td>
<td>trivial</td>
</tr>
<tr>
<td>Vertical impulse (m/s)*</td>
<td>0.54</td>
<td>0.07</td>
<td></td>
<td>0.59</td>
<td>0.08</td>
<td>0.01</td>
<td>−0.60</td>
<td>medium</td>
</tr>
<tr>
<td>Mediolateral impulse (m/s)*</td>
<td>0.23</td>
<td>0.10</td>
<td></td>
<td>0.08</td>
<td>0.05</td>
<td>&lt;0.01</td>
<td>1.48</td>
<td>large</td>
</tr>
<tr>
<td>Resultant impulse (m/s)</td>
<td>3.27</td>
<td>0.15</td>
<td></td>
<td>3.25</td>
<td>0.16</td>
<td>0.32</td>
<td>0.12</td>
<td>trivial</td>
</tr>
<tr>
<td>$P_{NAHB}$</td>
<td>0.46</td>
<td>0.07</td>
<td></td>
<td>0.45</td>
<td>0.07</td>
<td>0.33</td>
<td>0.09</td>
<td>trivial</td>
</tr>
<tr>
<td><strong>1st Step</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anteroposterior GRF (BW)</td>
<td>0.64</td>
<td>0.06</td>
<td></td>
<td>0.63</td>
<td>0.04</td>
<td>0.32</td>
<td>0.28</td>
<td>small</td>
</tr>
<tr>
<td>Mediolateral GRF (BW)*</td>
<td>−0.16</td>
<td>0.05</td>
<td></td>
<td>−0.08</td>
<td>0.04</td>
<td>&lt;0.01</td>
<td>1.49</td>
<td>large</td>
</tr>
<tr>
<td>Vertical GRF (BW)</td>
<td>1.36</td>
<td>0.09</td>
<td></td>
<td>1.35</td>
<td>0.13</td>
<td>0.84</td>
<td>0.05</td>
<td>trivial</td>
</tr>
<tr>
<td>Resultant GRF (BW)</td>
<td>1.51</td>
<td>0.10</td>
<td></td>
<td>1.49</td>
<td>0.12</td>
<td>0.54</td>
<td>0.18</td>
<td>trivial</td>
</tr>
<tr>
<td>Net Anteroposterior impulse (m/s)</td>
<td>1.29</td>
<td>0.06</td>
<td></td>
<td>1.26</td>
<td>0.04</td>
<td>0.07</td>
<td>0.54</td>
<td>medium</td>
</tr>
<tr>
<td>Braking impulse (m/s)</td>
<td>0.04</td>
<td>0.04</td>
<td></td>
<td>0.03</td>
<td>0.02</td>
<td>0.34</td>
<td>0.13</td>
<td>trivial</td>
</tr>
<tr>
<td>Propulsive impulse (m/s)*</td>
<td>1.33</td>
<td>0.06</td>
<td></td>
<td>1.29</td>
<td>0.05</td>
<td>0.04</td>
<td>0.59</td>
<td>medium</td>
</tr>
<tr>
<td>Vertical impulse (m/s)</td>
<td>0.71</td>
<td>0.18</td>
<td></td>
<td>0.71</td>
<td>0.28</td>
<td>0.94</td>
<td>0.02</td>
<td>trivial</td>
</tr>
<tr>
<td>Net Mediolateral impulse (m/s)*</td>
<td>0.33</td>
<td>0.10</td>
<td></td>
<td>0.17</td>
<td>0.10</td>
<td>&lt;0.01</td>
<td>1.48</td>
<td>large</td>
</tr>
<tr>
<td>$P_{P_{NAH}}$</td>
<td>0.78</td>
<td>0.09</td>
<td></td>
<td>0.73</td>
<td>0.17</td>
<td>0.18</td>
<td>0.36</td>
<td>small</td>
</tr>
</tbody>
</table>

*Significant difference between Skating and Narrow trials (p < 0.05).
CoM and performance during the block and 1st stance phase of a sprint start. Our first hypothesis that mediolateral impulses decreased with reduced step width was confirmed. The second hypothesis, that block and in 1st stance net anteroposterior impulses would increase with reduced step width, could not be confirmed; in fact the propulsive component of the net anteroposterior impulse was significantly smaller for the narrow step width in the 1st stance. Furthermore it was found that by restricting step width, vertical block impulses increased while the mediolateral motion of the CoM from Start to 1st stance toe-off decreased.

Although reducing step width did not affect block performance as measured by $P_{NAHB}$ it did cause a reduction in mediolateral block impulses and an increase in vertical block impulses. These differences can also be seen in the average 3D GRF vectors (Figure 5). Reducing step width caused a reduction in $GRF_{MED}$ and average mediolateral block vectors and an increase in the average vertical block GRF vector. The greatest differences between the skating and narrow styles during the block phase were seen in the mediolateral direction. Although the mediolateral impulses are the smallest of the three, they are not negligible. An increase in the vertical impulse could cause a greater block exit angle, and since a high block exit angle is detrimental to performance (Harland & Steele, 1997) it is possible that there exists a small trade-off in terms of pushing direction. Thus, the athletes who use a skating style could be prioritising a reduction in vertical motion and a more lateral motion during the starting block phase.

The mean relative anteroposterior block impulse found in this study (3.2 m/s) was similar to those reported by Coh, Jost, Skof, Tomazin, and Dolenec (1998) for sprinters of similar ability. The $P_{NAHB}$ found in this study (0.458) was similar to the average of a cohort of sprinters of 0.51 reported by Bezodis et al. (2010). The average normalised step length and $P_{NAHB}$ was similar to that reported in the studies of Bezodis et al. (Bezodis et al., 2014; Bezodis, Salo, & Trewartha, 2015). Although the step widths found in this study (0.31 m) were similar to the 1st stance step width of 0.31 m reported by Otsuka et al. (2014), the mean relative mediolateral block impulse of 0.23 m/s found in this study was nearly double.
Figure 3

(continued from previous page)

that of 0.14 m/s reported by Otsuka et al. (2014) for sprinters of similar ability, height and weight. The reason for this difference in reported mediolateral impulses is unclear.

Both 1st stance toe-off anterior velocity and the 1st stance relative propulsive impulse were greater for the skating style with no change in contact time. This suggests that the athletes performed better when they performed their natural skating style start. On the other hand, neither the net relative anteroposterior impulse nor the $P_{\text{NAH}}$ were significantly different though their medium and small effect sizes, respectively, suggested a possible positive effect of the skating style. Since the t-test is sensitive to sample size it is possible that a greater sample size may well have shown a significant difference for both the net relative anteroposterior impulse and the $P_{\text{NAH}}$.

Reducing the step width resulted in lower mediolateral block forces and impulses, in conroboration with findings on running by McClay and Cavanagh (1994). In accordance with the laws of motion the greater mediolateral motion of the CoM seen during the skating trials (Figure 3) reflects the greater external mediolateral forces during the block and first stance phases. Therefore, the athletes push more in the mediolateral direction when performing a skating style start, confirming our hypothesis.

A possible reason why sprinters have a wide first step, may be found by considering the musculoskeletal geometry of the hip joint. The importance of the hip muscles to generate joint power during block starts has been highlighted by several studies (Bezodis et al., 2015; Brazil et al., 2017; Mero, Kuitunen, Harland, Kyrolainen, & Komi, 2006). The hip joint is spanned by over 20 muscles (Weißgraeber, V.D. Wall, Khabbazeh, Kroker, & Becker, 2012). The largest muscles that contribute to extension of the hip during the block phase are the gluteus maximus and biceps femoris, and both show high electromyographic activity during this phase (Čoh, Peharec, Bačić, & Kampmiller, 2009; Mero & Komi, 1990). The gluteus medius, which is primarily a hip abductor, is also likely to be active to prevent the pelvis dropping on the swing leg side (Wiemann & Tidow, 1995).

Not only do the moment arms of these muscles have components in the three anatomical planes (Blemker & Delp, 2005; Wiemann & Tidow, 1995), but the magnitudes of these moment arms will vary as the joint angle changes, i.e., muscle function changes with changing joint position (Zatsiorsky & Prilutsky, 2012). Therefore, it is likely that during hip extension of the leading leg whilst the athlete is pushing against the starting blocks with maximum force, the hip extensors’ (and possibly abductors’) muscle moment arms change to include a hip abduction and external rotation component. The consequence of this is that whilst rising from a crouched position the highly active hip musculature could contribute to a lateral (towards the 1st step leg) acceleration and cause the athlete to move contralaterally during the front push on the starting blocks. This hypothesis could be examined using EMG analysis combined with musculoskeletal modelling in future studies.

The obvious limitation of this study is the length of the measurement space. However, as described in the Methods section, the results from a pilot study indicated that the laboratory setting was adequate for testing the hypothesis of this study. Another limitation is the normal decline in performance commonly observed when learning a new technique (Schmidt & Lee, 2011). Although the athletes were given as many practise trials as they felt necessary, they are limited to the number of trials that can be performed with maximal effort before becoming fatigued.

From a practical point of view, the data presented for the group of athletes included in this study suggest that reducing step width is unlikely to cause an immediate improvement to performance for the majority of athletes, however, a coach should bear in mind the limitations of this study.

Conclusion

Considerable mediolateral impulses and mediolateral deviation of the CoM were found to be a natural part of sprint acceleration when utilising a skating style sprint start technique using starting blocks. By reducing step width, a reduction in mediolateral impulses and mediolateral deviation of the CoM was seen, which did not lead to any immediate improvement in performance. On the contrary, the skating style was shown to have a greater propulsive impulse during the first stance.

Acknowledgments

The authors are grateful to Fredrik Tinmark and Olga Tarrassova at GfH for their assistance with the empirical data collection and Torbjörn Eriksson at Svensk Friidrott for allowing his elite sprinters to participate in this study.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the The Swedish Research Council for Sport Science [P2015-0029].

References


