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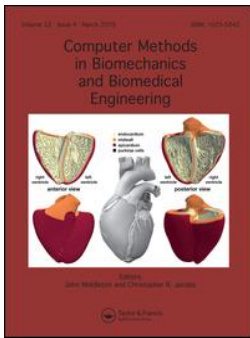
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# Influence of pole carriage on sprint mechanical properties during pole vault run-up

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**KEYWORDS** pole vaulting; force-velocity profile; power

## 1. Introduction

Pole vault performance is highly correlated with the final running velocity of the athlete at take-off (Frère et al. 2010). To achieve top running velocity, the athlete has to develop a large forward acceleration, which is related to the ability to produce and apply a high amount of impulse onto the ground (Rabita et al. 2015). Although it is well known that carrying a pole impairs horizontal velocity output (Gros & Kunkel 1990), only few studies investigated the underlying mechanisms explaining this loss of velocity. For instance, Frère et al. (2009) found in novice athletes a reduction of maximal hip and knee flexion during 30-m sprints with pole carriage that induced a decrease in stride length, and thus, a lower horizontal velocity. However, mechanical changes due to the pole carriage and for a higher level of expertise remain unexplored.

This study aimed to characterise the changes in horizontal force- and power-velocity relationships induced by pole carriage, by means of a validated simple field model based on a macroscopic inverse dynamic approach (Samozino et al. 2016).

## 2. Methods

### 2.1. Athletes

Seventeen experienced pole vaulters (10 women, height:  $167 \pm 7$  cm, body mass:  $57 \pm 6$  kg, personal best:  $4.03 \pm 0.22$  m; 7 men, height:  $175 \pm 2$  cm, body mass:  $65 \pm 3$  kg, personal best:  $5.08 \pm 0.16$  m) volunteered to participate in this study.

### 2.2. Protocol

After an appropriate warm-up, athletes performed 2 maximal accelerations without pole and 2 with pole carriage

in a random order with 5 min of passive recovery between sprints. According to their usual run-up length during competition, men sprinted over a 40-m distance, while women sprinted over a 30-m distance. The athletes were instructed to run as fast as possible and to keep a constant pole-ground angle throughout the trial. The pole-ground angle corresponded to the one used in the first half of the usual run-up. Each athlete used her/his own vaulting pole meeting the imposed length and mass characteristics: 4.30 m for women and 4.90 m for men; 1.8 kg for women and 2.1 kg for men. All athletes were free of injury during this measurement session.

### 2.3. Measurements and data processing

For each sprint trial, a radar gun Stalker Pro II (Stalker Ltd, Plano, United states) was placed behind the athlete in the sprint direction at a 1.4 m height and allowed measuring the instantaneous horizontal velocity of the athlete (sampling rate of 46.9 Hz). This data flow was integrated into MookyStalker software (Matsport, Saint-Ismier, France) to export the raw velocity-time data, which were processed offline using Samozino's model (2016).

Briefly, the velocity-time data were fitted by an exponential function, which was then derived to estimate the net horizontal anteroposterior ground reaction force and the power output in the horizontal direction. From all of these mechanical data over time, individual linear force-velocity relationships were then extrapolated to calculate the force-velocity profile ( $S_{FV}$ ), which corresponded to the slope of the linear model, theoretical maximal force ( $F_0$ , in N/kg) and velocity ( $V_0$ , in m/s) capabilities. Finally, the power-velocity relationships were extrapolated by a 2nd order polynomial function to calculate the maximal power output ( $P_{max}$ , in W/kg). These relationships and

**Table 1** Mean ( $\pm$  standard deviation) values of the mechanical sprint variables without and with pole carriage. ES: Effect size; CL: confidence limits.

	Without pole	With pole	Percent change	ES $\pm$ 90% CL
$F_0$	6.56 $\pm$ 0.74	5.88 $\pm$ 0.62	-9.3 $\pm$ 13.0	-0.89 $\pm$ 0.55
$V_0$	9.29 $\pm$ 0.67	8.70 $\pm$ 0.57	-6.3 $\pm$ 4.0	-0.85 $\pm$ 0.23
$S_{fv}$	-0.71 $\pm$ 0.10	-0.68 $\pm$ 0.09	-3.0 $\pm$ 16.8	0.30 $\pm$ 0.53
$P_{max}$	15.03 $\pm$ 1.98	12.64 $\pm$ 1.4	-15.1 $\pm$ 10.2	-1.28 $\pm$ 0.41

mechanical variables were computed for all the trials and then averaged for each condition and each athlete.

## 2.4 Statistical analysis

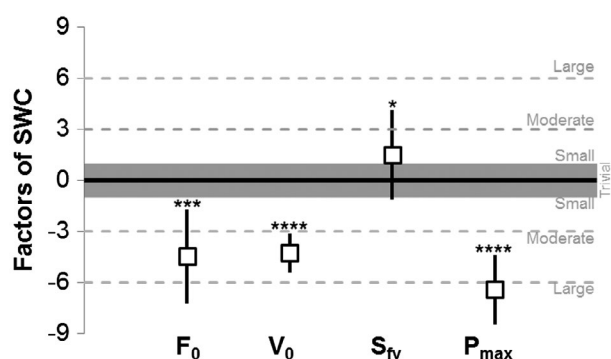
The effect of pole carriage was analysed using magnitude-based inferences with a smallest worthwhile change (SWC) value equal to a Cohen's  $d$  of 0.20 (Hopkins et al. 2009). The thresholds for small, moderate, and large standardized changes were  $1\times$ ,  $3\times$ ,  $6\times$  SWC, respectively. Probabilities that differences were higher than, lower than, or similar to the SWC were evaluated qualitatively as possibly, [25–75%], likely, [75–95%], very likely, [95–99.5%]; and most likely, >99.5%.

## 3. Results and discussion

Pole carriage led to very likely and most likely moderate decreases in  $F_0$  and  $V_0$ , respectively (Table 1 and Figure 1), while a possibly small increase in the force-velocity profile was found, along with a most likely large decrease in  $P_{max}$ .

Overall, these results showed, for the first time, that carrying a pole altered both horizontal force and velocity capabilities of the athlete. Both these decreases induced by pole carriage had a dramatic effect on the horizontal power production.

Additionally, the small increase in the force-velocity profile and the slightly higher magnitude effect on  $F_0$  than  $V_0$  (ES of -0.89 and -0.85, respectively) might suggest a little higher force-deficit with pole carriage. This specificity opens the question about the respective effects of the additional mass (of the pole), the arm-swing restriction or the level of expertise (*i.e.*, is it still true for world-class athletes?). Also, these results highlight a potential need to optimize the sprint training program to diminish this force-deficit associated with pole carriage. Such hypothesis emphasizes the interest in regularly monitoring the force-velocity relationships in sprinting with and without pole. Bringing these two profiles closer may help increase the running top speed at take-off which might be beneficial for the final performance (Frère et al. 2010).



**Figure 1** Magnitude of changes due to the pole carriage in the sprint acceleration mechanical outputs. The standardized differences are expressed as a factor of the SWC. Bar indicate the 90% confidence limits. \*: possibly; \*\*\*: very likely; \*\*\*\*: most likely probabilities of lower, similar or higher difference than SWC.

## 4. Conclusions

Pole carriage during sprinting induces a large decrease in power output due to simultaneous impairment in force and velocity capabilities.

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