The Effect of Muscular Pre-Tensing on the Sprint Start

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Pre-tensed and conventional starts that exert, respectively, large and small forces against the starting blocks in the “set” position (0.186 vs. 0.113 N per newton of body weight) were analyzed. The starts were videotaped, and the horizontal forces exerted on feet and hands were obtained from separate force plates. In the pre-tensed start, the legs received larger forward impulses early in the acceleration (0.18 vs. 0.15 N·s per kilogram of mass in the first 0.05 s), but the hands received larger backward impulses (–0.08 vs. –0.04 N·s·kg\(^{-1}\)). At the end of the acceleration phase, there was no significant difference in horizontal velocity between the two types of start and only trivial differences in the center of mass positions. The results did not show a clear performance change when the feet were pressed hard against the blocks while waiting for the gun.

Key Words: biomechanics, athletics, track and field

Preparations for the track and field sprint start begin with the starter’s “on your marks” command. In response, each athlete adopts a crouched position with both feet in contact with the starting blocks, and both hands and the knee of the rear leg on the ground (Figure 1a). After the starter’s “set” command, the athlete lifts the knee of the rear leg off the ground, shifting the body center of mass upward and forward, and then stays still in this position waiting for the starting gun (Figure 1b). After the starting gun is fired, there is a reaction time period during which the athlete remains still in the “set” position. Then the feet exert large backward forces against the blocks, the athlete accelerates forward, and takes off from the blocks (Figure 1b–g).

Some practitioners propose that the feet should press hard against the blocks while the athlete waits for the starting gun in the “set” position (Gordon, 1972; Schmolinsky, 1978; Gambetta et al., 1989; Martín-Acero, 1991; Pascua, 1998). This requires strong pre-tensing of the muscles that extend the legs. The expected advantage of such a technique is that the muscles, and therefore also the feet, will be able to exert larger forces during the early stages of the acceleration phase than if the muscles had been relaxed or activated more moderately before the gun is fired.

Of course, if an athlete presses backward against the blocks before the gun is fired, the reaction forces exerted by the blocks against the feet will tend to accelerate the athlete forward prematurely, and this would produce a false start. Therefore, any backward horizontal forces exerted by the feet against the blocks will need to be accompanied by forward horizontal forces exerted by the hands against the ground. The net horizontal force exerted on the athlete by the reactions to all these forces will need to be near zero while the athlete waits for the gun.

If an athlete’s leg muscles are not pre-tensed when the gun is fired, the forward force exerted by the blocks on the feet will be initially zero, and will gradually increase as the leg muscles become progressively more activated after the gun is fired.
If the athlete's muscles are already strongly pre-tensed when the gun is fired, the subsequent forward acceleration is produced by an increase in the forward force exerted by the blocks on the feet and a decrease in the backward force exerted by the ground on the hands. If the backward force exerted by the ground on the hands could be reduced to zero instantaneously, a starting technique with strong pre-tensing of the leg muscles in the “set” position would provide a clear advantage over a conventional starting technique with less pre-tension or no pre-tension in the “set” position: In the strongly pre-tensed start, the athlete would have available a substantial net forward force at the very beginning of the acceleration phase. However, muscles cannot be deactivated instantaneously (Brown & Loeb, 2000; Neptune & Kautz, 2001). Therefore, the arm muscles that make the hands press forward against the ground will only be able to deactivate gradually, the backward force exerted by the ground on the hands will not be eliminated instantaneously, and the net horizontal force exerted on the athlete will not jump instantaneously from zero to a substantial positive value. The change in the net forward force will be gradual, as the leg muscles progressively increase their levels of activation and the arm muscles that make the hands press forward gradually decrease their levels of activation or the hands are gradually pulled from ground contact. Because of this, it is impossible to judge beforehand if strong pre-tensing of the leg muscles before the starting gun is fired will provide an advantage, a disadvantage, or no effect at all.

This project examined the horizontal forces received by sprinters through the feet and through the hands in starts that used moderate and large amounts of pre-tension in the “set” position. The values of these forces were integrated to calculate the progression of the horizontal velocity and position of the center of mass during the acceleration phase. The purpose of the project was to compare the horizontal velocities and positions of the center of mass at the end of the acceleration phase when using these two techniques, and to draw inferences in regard to the possible net advantage of one technique over the other.

Methods

Data collection took place at the Palau Luis Puig indoor arena in Valencia, Spain. Nineteen experienced competitive male sprinters participated in the study (age = 20.6 ± 3.1 years; standing height = 1.79 ± 0.06 m; mass = 70 ± 7 kg; personal record in 100 m = 11.09 ± 0.30 s). Informed consent was obtained from the participants, following the guidelines of the Ethics Commission of the University of Granada.

On the day before the data collection session, the subjects practiced conventional starts with a moderate amount of backward force exerted against the blocks in the set position, and pre-tensed starts with maximal force exerted against the blocks in the set position, until they were able to differentiate clearly between the two types of start. This required a total of between six and ten starts for each subject. During the data collection session, each subject was instructed to perform five conventional starts and five pre-tensed starts. All starts of one type were performed first, and all starts of the other type were performed afterward; the order was alternated for each successive subject. The subjects were instructed to run as fast as possible in every trial to a finish line 10 m away from the start.

For each trial, the subject positioned himself on the starting blocks, and was allowed to set his hands on the ground wherever he chose. An
The automatic starting system produced a low-pitched sound to represent the “set” command and a high-pitched sound to represent the sound of the starting gun. To emulate the behavior of the starter during competitions, the time between the two sounds was varied randomly between extreme values of 1.5 s and 3.0 s. Ground reaction forces were obtained from two Dinascan/IBV force platforms (Instituto de Biomecánica de Valencia, Valencia, Spain) at a sampling rate of 250 Hz. Platform A (600 × 370 mm) was placed under the starting blocks; platform B (800 × 800 mm) was placed under the subject’s hands. (See Figure 2.) The starting system and the two force platforms were synchronized through an electronic signal produced by the starting system. Each subject was also videotaped from the side at 250 Hz with a Redlake MotionScope PCI 1000S high-speed digital video camera (Redlake Corporation, San Diego, CA).

In each trial, the average force values from the two force platforms were calculated for a 0.08-s period after the subject lost contact with the platforms (20 consecutive force samples). These baseline values were then subtracted from all other force platform readings.

The start of the acceleration phase was determined from the force platform records. It was estimated at 0.002 s (half an interval) before the instant when the net horizontal force first reached a value equal or larger than 1% of body weight. The end of hand support was estimated at 0.002 s before the first instant when the vertical force from platform B showed a negative value (owing to random noise in the force platform data). The end of the acceleration phase (takeoff of the second foot) was estimated at 0.002 s before the horizontal force from platform A showed the first negative value. Zero values were then assigned to all forces from platform B after the takeoff of the hands, and to all forces from platform A after the takeoff of the second foot. This eliminated low-level random noise from the force platform data during noncontact.

Horizontal acceleration was computed from the net horizontal force and the mass of the subject. Progressive horizontal velocities and locations were calculated from the horizontal acceleration-time values using trapezoidal integration.

For each subject, two trials were selected for full analysis: the trial with the median horizontal velocity value at the end of the acceleration phase.

**Figure 2** — Force platform set-up.
in each of the two conditions. Comparisons were made between these two trials.

The level of pre-tension in each analyzed trial was evaluated by the amount of forward force exerted by the blocks against the feet at the instant when the starting system produced the sound representing the shot of the starter’s gun.

We considered the possibility that there might be some systematic differences between the conventional and pre-tensed conditions in regard to the duration of the acceleration phase and to the horizontal range of motion traveled by the center of mass during the acceleration phase. To facilitate comparisons, the final part of the longer of the two selected trials of each subject was truncated to make both trials have the same horizontal range of motion during the acceleration phase. This produced “range-equated” trials. For some subjects, the truncated trial was the conventional one, and for others the pre-tensed one. In addition to the comparisons between the two full trials of each subject, comparisons were made between the two range-equated trials.

To examine in detail the early part of the acceleration phase—the period when the effects of pre-tensing should be expected to be most marked—the horizontal forces from the two force platforms during the first 0.05 s were divided by the mass of the subject to calculate the separate contributions of the legs and of the hands to the horizontal acceleration. Trapezoidal integration was then used to calculate the separate contributions of the legs and of the hands to the horizontal location of the center of mass of each subject relative to the forward edge of the hands (the “starting line”) just before the start of the acceleration period. Positive arm angles indicated that the shoulders were ahead of the wrists.

Paired t tests were used to check for statistically significant differences between the two conditions. The cut-off chosen for statistical significance was \( p = 0.05 \).

Results

Horizontal force values versus time for two representative subjects are shown in Figures 3a and 3b, respectively. All force values are expressed in newtons of force per newton of body weight. In the “set” position (i.e., preceding \( t = 0.00 \) s in the graphs of Figure 3), the forward forces exerted on the feet and the backward forces exerted on the hands were larger in the pre-tensed trials than in the conventional trials (top graphs), whereas the net force was approximately zero in both types of trials (bottom graphs). In the acceleration phase (which began at \( t = 0.00 \) s), the forward forces exerted on the feet increased, and the backward forces exerted on the hands decreased (top graphs). This produced a positive net horizontal force on the subject (bottom graphs). For some subjects, the net horizontal force during the earliest part of the acceleration phase was larger in the conventional trial (bottom graph in Figure 3a), for others in the pre-tensed trial (bottom graph in Figure 3b), and for still others it was approximately the same in both trials.

Numerical results are shown in Table 1. The force exerted by the feet on the blocks in the “set” position was larger in the pre-tensed start than in the conventional start (0.186 N/N vs. 0.113 N/N). The arm angle was smaller in the pre-tensed start than in the conventional start (2° vs. 6°), indicating that the line pointing from the wrist to the shoulder had less forward tilt in the pre-tensed start. In the “set” position, the center of mass was farther back from the starting line in the pre-tensed start than in the conventional start (0.346 m vs. 0.310 m). No statistically significant differences were found between the reaction times of the two types of start.

The velocity change contributed by the legs during the first 0.05 s of the acceleration phase was larger in the pre-tensed start than in the conventional start (0.18 m/s vs. 0.15 m/s), but the velocity lost through the backward force received by the hands was also larger in the pre-tensed start than in the conventional start (–0.08 m/s vs. –0.04 m/s). As
a result, there was no statistically significant difference between the two types of start in the net velocity produced during the first 0.05 s of the acceleration phase.

The duration of the acceleration phase and the horizontal range of motion covered by the center of mass during the acceleration phase were slightly longer in the pre-tensed start than in the conventional start (0.386 s vs. 0.375 s, and 0.619 m vs. 0.600 m). In spite of the longer horizontal range of motion traveled by the center of mass during the acceleration phase in the pre-tensed start, the center of mass was slightly farther forward relative to the starting line at the end of the acceleration phase in the conventional start than in the pre-tensed start (0.290 m vs. 0.274 m ahead of the starting line). This was due to the more backward initial location of the center of mass in the “set” position in the pre-tensed start. No statistically significant difference was found between the horizontal velocities in the two types of start at the end of the acceleration phase.

When the two types of start were range-equated for each subject by truncating the longer trial to

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**Figure 3** — Horizontal forces exerted on two representative subjects (a and b, respectively) in conventional and pre-tensed starts. Forces are expressed in newtons of force per newton of body weight. The top graphs show horizontal forces exerted on the hands and feet; the bottom graphs show resultant horizontal force. The force tracings start at the gunshot; \( t = 0.00 \) s corresponds with the beginning of motion.
Table 1  Characteristics of the Conventional and Pre-Tensed Starts

<table>
<thead>
<tr>
<th>Item</th>
<th>Conventional start</th>
<th>Pre-tensed start</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Before the acceleration phase</strong></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Initial force on blocks</td>
<td>0.113 ± 0.04 N/N</td>
<td>0.186 ± 0.053 N/N</td>
<td>p &lt; 0.001</td>
</tr>
<tr>
<td>Arm angle</td>
<td>6 ± 6°</td>
<td>2 ± 6°</td>
<td>p &lt; 0.001</td>
</tr>
<tr>
<td>Initial distance from center of mass to starting line</td>
<td>0.310 ± 0.057 m</td>
<td>0.346 ± 0.068 m</td>
<td>p &lt; 0.001</td>
</tr>
<tr>
<td>Reaction time</td>
<td>0.139 ± 0.018 s</td>
<td>0.142 ± 0.024 s</td>
<td></td>
</tr>
<tr>
<td><strong>First 0.05 s of acceleration phase</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity produced by legs</td>
<td>0.15 ± 0.04 m/s</td>
<td>0.18 ± 0.04 m/s</td>
<td>p &lt; 0.02</td>
</tr>
<tr>
<td>Velocity lost by hands</td>
<td>−0.04 ± 0.02 m/s</td>
<td>−0.08 ± 0.03 m/s</td>
<td>p &lt; 0.001</td>
</tr>
<tr>
<td>Net velocity produced</td>
<td>0.11 ± 0.04 m/s</td>
<td>0.10 ± 0.04 m/s</td>
<td></td>
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<tr>
<td><strong>Entire acceleration phase</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duration</td>
<td>0.375 ± 0.028 s</td>
<td>0.386 ± 0.036 s</td>
<td>p &lt; 0.05</td>
</tr>
<tr>
<td>Horizontal range of motion</td>
<td>0.600 ± 0.046 m</td>
<td>0.619 ± 0.059 m</td>
<td>p &lt; 0.02</td>
</tr>
<tr>
<td>Final distance from center of mass to starting line</td>
<td>0.290 ± 0.060 m</td>
<td>0.274 ± 0.072 m</td>
<td>p &lt; 0.05</td>
</tr>
<tr>
<td>Final velocity</td>
<td>3.21 ± 0.22 m/s</td>
<td>3.23 ± 0.25 m/s</td>
<td></td>
</tr>
<tr>
<td><strong>Range-equated acceleration phase</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Duration</td>
<td>0.373 ± 0.029 s</td>
<td>0.378 ± 0.032 s</td>
<td></td>
</tr>
<tr>
<td>Horizontal range of motion</td>
<td>0.594 ± 0.052 m</td>
<td>0.594 ± 0.052 m</td>
<td>N/A</td>
</tr>
<tr>
<td>Final distance from center of mass to starting line</td>
<td>0.284 ± 0.063 m</td>
<td>0.248 ± 0.077 m</td>
<td>p &lt; 0.001</td>
</tr>
<tr>
<td>Final velocity</td>
<td>3.21 ± 0.22 m/s</td>
<td>3.22 ± 0.24 m/s</td>
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</tr>
</tbody>
</table>

make both trials have the same horizontal range of motion during the acceleration phase, the difference in the final horizontal velocity remained statistically nonsignificant, and the difference in the duration of the acceleration phase became statistically nonsignificant.

**Discussion**

As expected, the pre-tensed start allowed the generation of larger backward forces with the feet in the early part of the acceleration phase. However, it also required the exertion of larger forward forces with the hands during the same period of time. The advantage of the former was cancelled by the disadvantage of the latter, and overall the pre-tensed start had little influence on performance.

Before the start of the acceleration phase, the line pointing from the wrist to the shoulder had less forward lean in the pre-tensed start than in the conventional start. This may have facilitated the exertion of increased forward force by the hands against the ground in the “set” position of the pre-tensed start, and therefore permitted the exertion of increased backward force by the feet against the starting blocks without producing a false start. However, it also contributed to a slight disadvantage of 0.036 m in the initial horizontal position of the center of mass in relation to the conventional start.

The horizontal force exerted on the feet during the acceleration phase followed a bimodal pattern in all trials, with the first peak higher than the second. This was similar to the pattern reported by Payne & Blader (1971). The hands were subjected initially to a backward force. During the acceleration phase, this force decreased in magnitude and, in most cases, acquired a positive value before the hands left the ground.

Any advantage in propulsion attained through the pre-tensed start should be most visible in the early part of the acceleration phase. However, no such advantage was found during this period. As expected, during the first 0.05 s of the acceleration phase the horizontal impulse exerted by the blocks on the feet was larger in the pre-tensed start than in the conventional start, as indicated by the larger contribution of the legs to horizontal velocity. However, during this period the backward horizontal impulse exerted by the ground on the hands was also larger in the pre-tensed start than in the conventional start,
as indicated by the larger negative contribution of the hands to horizontal velocity. As a result, the pre-tensed trials showed no advantage in horizontal velocity at the end of the first 0.05 s of the acceleration phase. The advantage gained in the pre-tensed start by the increased backward force exerted by the feet against the blocks was apparently negated by the subjects’ limited capability to deactivate the muscles that made the hands push forward against the ground.

The pre-tensed start also showed no statistically significant advantage in the velocity of the center of mass at the end of the acceleration phase. This was not surprising, given the lack of net propulsive advantage during the early part of the acceleration phase.

In the pre-tensed start, the horizontal range of motion of the center of mass during the acceleration phase was 0.019 m longer than in the conventional start (0.619 m vs. 0.600 m), and the duration of the acceleration phase was 0.011 s longer (0.386 s vs. 0.375 s). Owing to the initial disadvantage of 0.036 m in the pre-tensed start’s center of mass location in the “set” position, at the end of the acceleration phase the center of mass remained 0.016 m behind in the pre-tensed start relative to the conventional start (0.274 m vs. 0.290 m). The less-advanced position of the center of mass at the end of the acceleration phase and the longer duration of the acceleration phase were slightly detrimental for the pre-tensed start.

The range-equated version of the starts facilitated the comparison of the two types of start. In the range-equated start, the horizontal range of motion became the same for both types of start, the difference in the duration of the acceleration phase became statistically nonsignificant, and the difference in the final velocity remained statistically nonsignificant. This implied that the average net propulsive forces were similar in the two types of start, and that the main reason why the full acceleration phase of the pre-tensed start lasted a longer time was that the athlete went through a longer horizontal range of motion in that start. At the end of the range-equated version of the start, the point where the center of mass completed its first 0.594 m of forward motion, there were no statistically significant differences between the two types of start in regard to time elapsed or to horizontal velocity, and there was only a slight disadvantage of 0.036 m in the position of the center of mass in the pre-tensed start.

In summary, the pre-tensed and conventional starts produced similar performance for the subjects in our sample. The increased propulsive force exerted through the legs in the early part of the acceleration phase in the pre-tensed starts did not result in a clear-cut advantage because it was counteracted by an increased backward force exerted through the hands during the same time period.

The results of this project do not necessarily imply that both types of start are equally effective for all athletes. Most of the subjects in our sample stated that they normally apply only moderate or small amounts of force against the blocks in the “set” position of their normal competition starts; only 2 of our 19 subjects stated that they habitually apply a large amount of force. It is possible that insufficient expertise in the execution of the pre-tensed start may have limited the average performance of our subjects in this type of start, and that perhaps subjects with greater expertise in both types of start might have performed better in the pre-tensed start. Taking this into consideration, we must conclude that the pre-tensed start is no worse than the conventional start, and that for subjects fully experienced in both types of start it is possible that the pre-tensed start might be more effective than the conventional start.

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References


