A brief description of the biomechanics and physiology of a strongman event: The tire flip

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ABSTRACT

The purpose of this study was to: 1) characterize the temporal aspects of a popular strongman event, the tyre flip; 2) gain some insight into the temporal factors that could distinguish the slowest and fastest flips; and 3) obtain preliminary data on the physiological stress of this exercise. Five resistance-trained subjects with experience in performing the tyre flip gave informed consent to participate in this study. Each subject performed two sets of six tyre flips with a 232 kg tyre with three minutes rest between sets. Temporal variables were obtained from video cameras positioned 10 m from the tyre, perpendicular to the intended direction of the tyre flip. Using the “stopwatch” function in Silicon Coach, the duration of each tyre flip as well as that of the first pull, second pull, transition and push phases were recorded. Physiological stress was estimated via heart rate (HR) and finger-prick blood lactate (BLa) response. Independent T-tests revealed that the two faster subjects (0.38 ± 0.17 s) had significantly (p < 0.001) shorter second pull durations than the three slower subjects (1.49 ± 0.92 s). Paired T-tests revealed that the duration of the second pull for each subject’s fastest three trials (0.55 ± 0.35 s) were significantly (p = 0.007) less than their three slowest three trials (1.69 ± 1.35 s). Relatively high HR (179 ± 8 bpm) and BLa (10.4 ± 1.3 mmol.L⁻¹) values were found at the conclusion of the second set. Overall, the results of this study suggest that the duration of the second pull is a key determinant of tyre flip performance and that this exercise provides relatively high degrees of physiological stress.

Keywords: Biomechanics, physiology, strongman, weight training.
INTRODUCTION

Many strength and conditioning specialists are now beginning to incorporate strongman exercises into their regular conditioning programs (7, 8, 13, 15). Strongman training might have some advantages over more traditional gym-based resistance training approaches as most human movements involve predominantly horizontal motion that occurs as result of unilateral ground reaction force production. This contrasts with most traditional gym-based resistance training exercises that are vertical in nature and are performed with the two feet side by side. While some practitioners advocated the use of lunges (11) and split stance Olympic lifts (10) to offset some of these limitations of the traditional lifts, strongman exercises may be even more applicable as they often involve unstable and awkward resistances and would appear to require the production of high horizontal as well as vertical unilateral forces. The inclusion of strongman exercises such as the tyre flip, sled pull and yoke walk along with more common lifts such as the power clean, snatch and squat may therefore further improve the performance and trunk stability of many athletic groups (8, 12, 15).

Of particular interest to this study is the tyre flip. The tyre flip requires a heavy tyre (that is initially lying flat on the ground) to be flipped end-over-end as quickly as possible for a set distance or number of repetitions. The athlete will crouch down in front of the tyre, grab the underside of the tyre with a supinated grip approximately shoulder width apart and via forceful ankle, knee, hip and back extension attempt to flip the tyre over. According to the recommendations of Havelka (6) and Hedrick (9), the tyre flip may be composed of several phases, these being the: 1) initial pull; 2) second pull; 3) transition where the hands come off the tyre; and 4) push, where the hands are repositioned on the tyre so to push the tyre over.
Only two scientific studies appear to have been conducted on any of the strongman events. McGill et al. (12) estimated the lower back loads and hip torque of three strongman performing a number of events such as the tyre flip, Atlas stones, log lift, farmers walk and yoke walk. These lifts were characterized by very high spine compression and shear forces, joint torques and activity of many of the hip and trunk stabilizers (12). Berning et al. (1) quantified the physiological demands of pushing and pulling a heavy car a distance of 400 m. The athletes reached 70% VO₂max and 96% of maximum heart rate (HR), recorded a blood lactate (BLa) concentration of 16 mmol.L⁻¹ and suffered an acute decrement in vertical jump height of 10 cm (17% of maximum) immediately after performing these tasks (1).

The purpose of this study was to: 1) characterize the temporal aspects of the tyre flip; 2) gain some insight into the temporal determinants of the tyre flip by comparing the three fastest and slowest flips from each athlete; and 3) obtain preliminary data on the physiological stress imposed by the tyre flip on the system via HR and BLa analysis. It was hypothesized that: 1) the first and second pull of the tyre flip would take longer to complete than other phases of the lift; 2) the duration of the second pull may be significantly longer in the slowest than fastest flips; and 3) the tyre flip would produce high HR and moderately high BLa responses.

METHODS

Approach to the Problem

The present study used a cross-sectional approach to examine some biomechanical and physiological aspects of a strongman event, the tyre flip. Specifically, this study focused on
characterizing the temporal components (phases) of the tyre flip and on gaining some insight into how the duration of these phases may relate to performance. Insight into the temporal determinants of tyre flip performance was achieved via between- and within-subject comparisons. Changes in HR and BLa across multiple time-points were also examined.

Subjects

Five male subjects (25 ± 7 years, mass 90 ± 6 kg, height 180 ± 6 cm) participated in this study. All five had extensive resistance training experience and four had competed in at least one strongman competition in which the tyre flip was an event. Testing was conducted in the early-mid part of their competitive seasons. Subjects were informed of the experimental risks and signed an informed consent form prior to the investigation. The investigation was approved by an Institutional Review Board for the use of human subjects.

Procedures

Subjects completed a warm-up which consisted of several sub-maximal sets of deadlifts and power cleans for approximately 10 minutes. This was followed by 2-4 repetitions of the tyre flip, performed in sets of 1-2 repetitions with moderate rest periods between each repetition and/or set. After completing their warm-up, the subjects performed two sets of six tyre flips with the goal being to perform each repetition and set as quickly as possible.

Several methods could have been used to record the duration of the different phases of the tyre flip. While manual panning was considered (4, 14), this would have resulted in substantial parallax error and a reduction in resolution. Accordingly, three stationary video
cameras were used. After each flip, the subjects typically jogged to the other end of the tyre so to begin the next flip in the shortest period of time possible. This meant that all odd number (#1, 3 and 5) flips went in one direction and all even number (#2, 4 and 6) flips went in the opposite direction. A rest period of three minutes was given between the two sets as is generally recommended for similar forms of training (3, 6). The tyre had a mass of 232 kg, external diameter of 1.50 m and a height when lying on the ground of 0.52 m.

**Biomechanical Measures**

Temporal variables relating to tyre flip performance were recorded by the digital video cameras (Sony, PAL, 50Hz, 1/1000 s) that were positioned 0.8 m above the ground at a distance of 10 m to the closest edge of the tyre. Camera 1 was 0.26 m past the tyre with respect to subject’s starting position so to be equidistant to the tyre’s expected position across the odd and even numbered repetitions. The field of view of Camera 1 was approximately twice the width of the other cameras so that it could record all tyre flips in each set and hence give a measure of total duration of each set of six repetitions. The other two cameras were positioned in line with the centre of the tyre in the starting position for the odd number lifts (Camera 2) and its expected position after the first flip for the even number lifts (Camera 3). Camera 2 and 3 were positioned on opposite sides of the tyre so that they both focused on the right side of the subjects as they performed the odd and even number repetitions, respectively. Because of their smaller field of view and hence greater resolution, these two cameras were used to assess the temporal measures of each odd and even repetition, respectively. A schematic of the experimental set-up is presented in Figure 1.

INSERT FIGURE 1 about here
**Physiological Measures**

Some indicators of the physiological stress involved with the tyre flip were gained by monitoring the HR and BLa response of the subjects. Heart rate was monitored by a chest-mounted Polar 625X heart rate monitor (Polar, Auckland, New Zealand). The BLa response was determined via finger-prick. The capillary blood from the finger-pricks were immediately analyzed by a validated portable lactate analyzer (Accusport, Boehringer Mannheim, Germany) (2). These two physiological measures were taken at five time-points (T0-T4). A pictorial representation of this is given in Figure 2.

**Data Analysis**

All video footage was analyzed using the “stopwatch” function Silicon Coach Pro video analysis software (Dunedin, New Zealand). The “stopwatch” function allowed the determination of the time at which five key tyre flip positions were reached. These positions were when the: 1) tyre was first lifted from the ground; 2) tyre first reached a height above the knee; 3) hands were initially taken off the tyre; 4) hands were repositioned on the tyre in readiness for the push; and 5) tyre reached a vertical position (see Figure 3). From these five positions, total flip time as well as the duration of the first pull, second pull, transition and push phases was calculated. Definitions for these phases are given below.

*Total flip time:* Time from when the first part of the tyre came off the ground to it rising to a vertical position (Fig 3a – Fig 3e).
**First pull:** Time from when the first part of the tyre came off the ground to it rising vertically past the knee joint (Fig 3a – Fig 3b).

**Second pull:** Time taken from the end of the first pull (i.e. tyre just above knee height) to when the hands are last taken off the tyre prior to the push (Fig 3b – Fig 3c).

**Transition:** Time taken from when the hands last left the tyre until the hands were repositioned on the tyre prior to the push (Fig 3c – Fig 3d).

**Push:** Time from when the hands are last repositioned on the tyre until the tyre reaches the vertical position (Fig 3d – Fig 3e).

Statistical Analyses

Standard descriptive statistics (means and standard deviations - s) were calculated for all dependent variables. For the temporal variables, this was initially done across the entire 60 trials. An a-priori within-subject analysis was then performed using two-tailed paired T-tests and effect sizes (ES) to compare the three slowest and fastest flips of each subject to examine the effect of fatigue on tyre flip performance. Inspection of the group mean data revealed high variability in the duration of the second pull. Thus, a between-subject analysis using two-tailed independent T-tests and ES was performed to compare the two subjects with a faster mean second pull than first pull duration to the remaining three subjects. Two-tailed paired T-tests and ES were also used to compare the change in HR and BLa from one time-point to the next (T0-T4). All statistical analyses were conducted using SPSS ver 14.0 with significance set at \( p \leq 0.05 \). As described by Drinkwater et al. (5) for sport science research,
the magnitude of the effect was given by the ES, whereby ES < 0.2 were defined as trivial, 
ES = 0.2-0.6 as small, ES = 0.6 – 1.2 as moderate and ES > 1.2 as large.

No power analysis was performed for this study. This was due to the exploratory nature of 
this pilot study and to the complete lack of data with which to conduct such an analysis. The 
test-retest reliability of all temporal measures was high (ICC = 0.96-0.99, CV = 2.1-8.5%).

RESULTS
The temporal characteristics of selected phases of the tyre flip are presented in Table 1. 
Inspection of the group mean data indicated that the transition phase had by far the shortest 
duration, with the second pull tending to be the longest.

INSERT TABLE 1 about here

Faster subjects (those with a shorter duration second pull than first pull) had significantly 
quicker total flip times than those with a longer second pull (see Table 2). These two faster 
subjects also had significantly shorter durations for the first pull and push phases than the 
slower subjects. The magnitude of these effects were much greater for the second pull (ES = 
-2.03) and the push phases (ES = -1.95) than the first pull (ES = -0.83).

INSERT TABLE 2 about here

Results for each subjects’ three fastest and three slowest flips is provided in Table 3. The 
fastest flips required significantly less time to complete the first and second pull than the
slowest flips. However, the magnitude of these effects were much greater for the second pull (ES = -1.34) than the first pull (ES = -0.67).

The HR and BLa concentrations significantly increased over the two sets of tyre flips. At the immediate post-set time-points (T1 and T3), HR was significantly \( (p < 0.001) \) greater than all other time-points (T0, T2 and T4). For BLa response, all pair-wise comparisons were significantly different \( (p = 0.001-0.017) \) with the exception of the two post-test (T3 vs T4) values \( (p = 0.886) \). Effect size analyzes indicated that all of the significant changes in HR (ES = 4.28-4.83) and BLa (ES = 1.66-5.17) were large in magnitude.

DISCUSSION

The results of this study provide the first normative data on the temporal aspects of any strongman event and give some insight into the temporal determinants of performance. Consistent with coaching recommendations (6, 9), the subjects generally attempted to use a four phase movement pattern (first pull, second pull, transition and push) to complete the tyre flip. Of the four phases analyzed, the group mean results demonstrated that the second pull required the greatest time to complete, with the transition phase being by far the shortest. Such a result was somewhat consistent with our initial hypothesis, whereby we expected the first and second pull to be the phases of the longest duration. The first pull was expected to have a relatively long duration because the length of the tyre’s resistance moment arm and
hence its resistance torque was maximized when the tyre was horizontal at the start of the first pull. Similarly, the duration of the second pull was also hypothesized to be relatively long as the resultant muscular torque in this phase was likely to be substantially less than that of the first pull due to changes in the primary agonists and to the force potential of these muscles as a result of the changes in the force-length and force-velocity relationships.

Greater variability in the overall group’s results was observed for duration of the second pull than the other three phases. As a result of this variability, we inspected each subjects’ mean results to see if this variability reflected a within- or between-subject effect. Results indicated a significant between-subject effect, with two of the subjects having a second pull duration that was shorter than that of the first pull and push phases. Interestingly, these two subjects’ total flip time was about half that of the other three subjects. Of further note, the increased time required by the slower subjects to complete the second pull (1.12 s) accounted for ~67% (1.66 s) of the between-group difference in the mean duration of each tyre flip. A within-subject analysis involving each subjects’ three fastest and slowest flips was also performed to examine the effect of fatigue on tyre flip performance. Results indicated that the duration of the second pull was significantly longer in the slowest than fastest flips, with this accounting for ~78% (1.14 s) of the increase in total flip time (1.46 s). The results of these between- and within-subject analyses offer strong support for the proposition that the ability to complete the second pull as quickly as possible is the primary temporal determinant of tyre flip performance.

The mean HR (~180 bpm) and BLa levels (~10.4 mmol.L⁻¹) achieved at the conclusion of the two sets of six tyre flips indicated that this resulted in a high degree of physiological stress.
Such a result is somewhat similar to that found by Berning et al. (1) for a 400 m car push/pull, whereby the subjects reached 70% VO$_{2}$max, 96% of maximum HR and recorded a BLa concentration of 16 mmol.L$^{-1}$. The duration of each set of six tyre flips in the current study (23-51 s) was substantially shorter than the 6-8 minutes for the car push/pull (1). However, Berning et al. (1) found that even after pushing/pulling the car 50 m (a distance that would have likely been completed in less than one minute), the subjects reached 44-49% VO$_{2}$max and 90-92% of maximum HR. Collectively, these results lend credence to the view that strongman exercises can impose a very high physiological demand on the system. It is therefore not surprising that a number of conditioners advocate such exercises for increasing anaerobic conditioning and/or energy expenditure (7, 8, 13, 15).

**Limitations**

As a pilot study involving only five moderately experienced strongman athletes, the current study is not without its limitations. The first concerns the manner in which the tyre flip was performed, whereby the subjects needed to alternate the direction of each flip based on the position of the camera. The second concern is that we only examined a small sub-set of important biomechanical (temporal) and physiological variables and that our temporal analysis only had a precision of 0.02 s. Future research in this area should incorporate larger sample sizes, utilize athletes of more elite levels, examine a greater range of variables e.g. joint kinematics, kinetics and/or electromyography (12) and determine the chronic effect of long-term strongman training on neuromuscular function.
PRACTICAL APPLICATIONS

The results of this study provide some of the first experimental data on any of the strongman events. As the between- and within-subject analyses indicated that the duration of the second pull was significantly longer in the slower tyre flips, it appears that this phase is the most critical temporal determinant of performance. Strongman competitors and athletes who use this exercise in training should therefore concentrate on improving this phase of the lift. This may be best achieved by selecting training loads that allow the second pull to be performed explosively. The high HR and BLa responses seen in this study and in the literature for the car push/pull also suggest that strongman exercises might prove useful in improving anaerobic conditioning and for increasing energy expenditure.
REFERENCES


Table 1: Group results for the durations of selected phase of the tyre flip.

<table>
<thead>
<tr>
<th>Duration (s)</th>
<th>(n = 60)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total flip time</td>
<td>2.90 ± 1.10</td>
</tr>
<tr>
<td>First pull</td>
<td>0.74 ± 0.08</td>
</tr>
<tr>
<td>Second pull</td>
<td>1.12 ± 1.03</td>
</tr>
<tr>
<td>Transition</td>
<td>0.15 ± 0.05</td>
</tr>
<tr>
<td>Push</td>
<td>0.95 ± 0.37</td>
</tr>
</tbody>
</table>

All data is mean ± SD.
Table 2: Durations for the selected phases of the tyre flip for the faster two and slower three subjects.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Faster Subjects</th>
<th>Slower Subjects</th>
<th>P Value</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(n = 24)</td>
<td>(n = 36)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total flip time (s)</td>
<td>1.90 ± 0.33 **</td>
<td>3.56 ± 0.91</td>
<td>&lt; 0.001</td>
<td>-2.68</td>
</tr>
<tr>
<td>First pull (s)</td>
<td>0.71 ± 0.07 **</td>
<td>0.77 ± 0.08</td>
<td>0.003</td>
<td>-0.83</td>
</tr>
<tr>
<td>Second pull (s)</td>
<td>0.38 ± 0.17 **</td>
<td>1.49 ± 0.92</td>
<td>&lt; 0.001</td>
<td>-2.03</td>
</tr>
<tr>
<td>Transition (s)</td>
<td>0.15 ± 0.03</td>
<td>0.15 ± 0.05</td>
<td>0.947</td>
<td>0.02</td>
</tr>
<tr>
<td>Push (s)</td>
<td>0.66 ± 0.17 **</td>
<td>1.14 ± 0.33</td>
<td>&lt; 0.001</td>
<td>-1.95</td>
</tr>
</tbody>
</table>

All data is mean ± SD. ** Significant (p < 0.01) difference between the fastest and slowest flips.
Table 3: Durations for the selected phases of the tyre flip for the fastest three and slowest three flips per subject.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Fastest Flips (n = 15)</th>
<th>Slowest Flips (n = 15)</th>
<th>P Value</th>
<th>Effect Size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total flip time (s)</td>
<td>2.26 ± 0.50 **</td>
<td>3.72 ± 1.48</td>
<td>&lt; 0.001</td>
<td>-1.48</td>
</tr>
<tr>
<td>First pull (s)</td>
<td>0.71 ± 0.07 *</td>
<td>0.76 ± 0.09</td>
<td>0.022</td>
<td>-0.67</td>
</tr>
<tr>
<td>Second pull (s)</td>
<td>0.55 ± 0.35 **</td>
<td>1.69 ± 1.35</td>
<td>0.007</td>
<td>-1.34</td>
</tr>
<tr>
<td>Transition (s)</td>
<td>0.15 ± 0.04</td>
<td>0.17 ± 0.06</td>
<td>0.462</td>
<td>-0.27</td>
</tr>
<tr>
<td>Push (s)</td>
<td>0.85 ± 0.28</td>
<td>1.10 ± 0.50</td>
<td>0.066</td>
<td>-0.64</td>
</tr>
</tbody>
</table>

All data is mean ± SD. * Significant (p < 0.05) difference between the fastest and slowest flips. ** Significant (p < 0.01) difference between the fastest and slowest flips.
**Figure Captions**

Figure 1: Schematic of the data collection procedures showing the location of the subject, tyre and cameras as well as the direction of the tyre flips. Note: this diagram is not necessarily drawn to scale.

Figure 2: Schematic of testing design and collection of physiological variables. T0 = immediately pre Set 1; T1 = immediately post Set 1; T2 = 2.5 minutes post Set 1 and immediately pre Set 2; T3 = immediately post Set 2; T4 = 2.5 minutes post Set 2. Heart rate and BLa measures were obtained at T0-T4.

Figure 3: Pictorial representation of the five positions of the tyre flip. A = start; B = tyre just above knee; C = hands leaving tyre; D = hands repositioned on tyre; E = tyre reached vertical position.

Figure 4: Heart rate and BLa response to tyre flipping. T0 = immediately pre Set 1; T1 = immediately post Set 1; T2 = 2.5 minutes post Set 1 and immediately pre Set 2; T3 = immediately post Set 2; T4 = 2.5 minutes post Set 2.
Figure 1

- Athlete
- Tyre
- Camera 1
- Camera 2
- Camera 3

Direction of 1st, 3rd and 5th repetitions
Direction of 2nd, 4th and 6th repetitions

10 m

1.50 m
Figure 2

T0    T1    T2    T3    T4
TYRE FLIP SET 1
1st THREE MINUTE REST
TYRE FLIP SET 2
2nd THREE MINUTE REST
THREE MINUTE REST
Figure 3
Figure 4

![Graph showing blood lactate and heart rate over time.

- **Blood Lactate (mmol.L⁻¹):**
  - T0: 0
  - T1: 2
  - T2: 4
  - T3: 6
  - T4: 8

- **Heart rate (bpm):**
  - T0: 80
  - T1: 100
  - T2: 120
  - T3: 140
  - T4: 160

- Time-points:**
  - T0
  - T1
  - T2
  - T3
  - T4

Legend:
- Vertical bars represent standard error of the mean (SEM).