Vertical Ground Reaction Forces during Walking in Patients with Low Back Pain before and after Physical Therapy

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Abstract

Background Although gait analysis provides an effective tool for evaluating and quantifying the effect of a given therapy on a patient's gait, knowledge is limited on the gait characteristics of people with low back pain (LBP). This study aims to evaluate the gait pattern of LBP patients referred for physiotherapy.

Methods The measurement of vertical ground reaction force (vGRF) was performed on an instrumented treadmill before beginning treatment during painful phases (pre-testing) and afterwards in pain-free phases (post testing).

Findings From 242 LBP patients with a mean age of 46.7 years (SD 14.6 years), 98 were male and 144 female. The vGRF curve was significantly flatter in pre- than in post-testing. First peak vGRF when full weight-bearing took place was slightly lower in pre- as in post-testing [(102.8%±10.6%, versus 103.6%±8.4% of body weight (BW)], and minimum at midstance remained unchanged (83.1% ± 7.8% BW versus 82.4%±9.1%). Peak of push-off forces (second peak) was statistically greater in post- compared with pre testing (107.3%±9.3% BW versus 104.4%±10.0%; *P*<0.001). Cadence and preferred speed were significantly higher after treatment (*P*<0.001). The differences between the first and second peaks of vGRF and the minimum at midstance were significantly greater in pain-free post-testing (21.1%±9.0% BW versus 19.6%±10% BW; p=0.015, 24.6%±10.2% BW versus 21.2%±9.8%; P<0.001).

Conclusion The present results showed that patients with LBP have typical gait patterns and typical shapes of the vGRF curve. Systematic inclusion of gait-analysis and -correction in the rehabilitation of patients with LBP could help achieve therapeutical aims rapidly and efficiently.

Key words

Vertical grounds reaction force, biomechanics, low back pain, gait analysis

Introduction

There is limited knowledge on the gait characteristics of people with low back pain (1) even though gait analysis provides an effective tool for evaluating and quantifying the effect of a given therapy or surgical intervention on a patient's gait. (2). The biomechanical measures include an evaluation of the forces exerted by weight bearing limbs on the ground, known as ground reaction forces (GRF), a direct application of Newton's third law of motion concerning action-reaction.

GRF can be applied to discriminate between normal and pathological gaits, as well as between pre- and post-treatment conditions.

Of the few studies performed concerning measurements of GRF, almost all compared the results of GRF in healthy individuals with the results of GRF in patients with different diseases and/or disorders. The differences in GRF were published for patients with LBP (1, 3), total hip arthroplasty (4), total knee arthroplasty (5, 6), total angle arthroplasty (7), amputations (8) and peripheral arterial disease (Scott-Pandorf, 2007). However, to our knowledge there are no studies comparing the same patients before and after treatment.

The aim of this study was to evaluate the vertical GRF during walking and to access if there is a typical gait pattern during the painful phase in patients with LBP before and in pain-free phases after physiotherapy.

Methods

From all patients referred for physiotherapy, a gait analysis was performed for 1004 patients. For this study, all adult patients diagnosed with LBP were included. The patients were referred from general physicians, rheumatologists and orthopaedics, and all were in painful phases of LBP.

The measurement of vertical ground reaction force (vGRF) was performed on an instrumented treadmill Kistler gaitway™, which measures the vGRF of consecutive strides of walking and running, collects the data from the force sensors located in the bed of the treadmill and separates these data into left and right foot strides.

The vertical components of GRF were collected before treatment in painful phases (pre-testing) and after completing physiotherapy, in pain-free phases (post-testing), respectively. The pre-measurement was performed during the first physiotherapy session after recording the patient's medical history, a physical examination as well as testing muscle status. After 10 minutes of adapting to treadmill walking, the patient then decided on the preferred speed of walking. The patient's weight was measured by the treadmill for data normalisation. Data were collected using a sampling frequency of 300 HZ. All patients performed treadmill walking barefoot to avoid influencing results by wearing different types of shoes. The average vGRF pattern was obtained for 10 seconds, corresponding with 6 to 8 complete strides, depending on speed, for the left and right sides producing vGRF curves, which were then analysed. If the shape of the vGRF curve showed a clear disturbance the patient was instructed to adjust his/her gait pattern by moving the centre of pressure upright to an angle of at least 5 to 0 degrees, and at the moment of heel contact, to flex the knee to a 20-25 degree angle. The measurements were repeated afterwards and following this the patient was treated for LBP. Treatment was suited to the patient's individual need, which may have included manual therapy, electrotherapy, an exercise regime, gait correction and/or gait re-education.

Gait analysis was performed in patients a second time in pain-free phases, barefoot and at the patient's preferred speed.

Statistical Analyses

Data are presented as percentages of cases for discrete variables and as a mean with standard deviation and/or median with an interquartile range from the 25th to the 75th percentile for continuous variables. Differences in pre- und post-testing were compared using the paired-samples t-test. A *P* value of <0.05 was considered significant. SPSS software (Chicago, Illinois; Version 14.0) was used for all statistical analyses.

Results

A total of 273 adult patients diagnosed with LBP were referred for physiotherapy. Gait analysis could not be performed for 31 (11%) patients who were unable to use the treadmill due to a disability.

From 242 patients between 16 and 78 years old, 98 were men with a mean age of 47.3years (SD 14.1 years), height of 180.1cm (SD 7.1cm), weight of 85.7kg (SD 18.0kg), BMI of 26.4 kg/m^2 (SD 5.0kg/m^2), and 144 were women with a mean age of 46.2 years (SD 15.0 years), height of 167.2cm (SD 6.6cm), weight of 68.9kg (SD 13.2kg) and with a BMI of 24.7kg/m^2 (4.8kg/m^2) respectively.

The time between pre- and post-measurements was 4 days (median) with an interquartile range of one to 24 days.

The results of the pre- and post-vGRF curves are depicted in table 1. First peak (F1) of vGRF when full weight-bearing takes place was slightly lower in pre-testing as in post-testing; expressed as percentage of body weight (BW) was 102.8% ±10.6%, versus 103.6% ± 8.4% (BW). Minimum at midstance (Fmin) remained unchanged between these two tests (83.1% ± 7.8% BW versus 82.4% ± 9.1% BW) but the second peak of push-off forces (F2) was statistically greater in post- compared to pre-testing (107.3% ± 9.3% BW versus 104.4% ± 10.0% BW). Cadence and preferred speed was significantly higher after treatment.

A normal gait pattern, characterized by morphology of vGRF, showed a typical bimodal pattern with reduced dispersion around the first and second peaks of force, good symmetry between the left and right sides, second peak (F2) was the same or greater than the first peak (F1) and the minimum at midstance (Fmin) was clearly lower. The vGRF curve was significantly flatter in pre- than in post-testing, caused by stiffness and shortening of the gluteus medius, gluteus minimus and piriforms. The differences between F1 and Fmin of vGRF and between F2 and

Fmin were significantly greater in pain-free post-testing, which expressed as percentage of BW was 21.1% ± 9.0% BW versus 19.6 ± 10% BW, 24.6% ± 10.2% BW versus 21.2% ± 9.8%, respectively as a result of improvement of muscle disbalance.

Figures 1 and 2 show typical examples of vGRF curves of patients with LBP pre- (Figures 1a, 2a) and post-treatment (Figures 1b, 2b). After treatment and/or gait correction, patients with diagnosed LBP were pain-free and the vGRF shapes recovered symmetry, with a clearly lower minimum at midstance and a higher second peak of vGRF nearing normal gait patterns.

Discussion

Patients with LBP during painful phases have an altered kinetic gait pattern during walking characterised by a significantly flatter vGRF curve compared with the steeper curve after treatment and gain correction (re-education) in the pain-free phases.

The causes of LPB are numerous and not clearly defined. LPB could be related to changes of the lumbal spine and the hip extensor recruitment pattern (9). Spine instability, injures and impairment of feedback control also have implications for LBP (10). A slight increase in muscle activation could elevate muscle contraction above the critical threshold, resulting in fatigue-related pain and painful muscle spasms could occur without injury or loss of spine stability (10).

LBP affects walking and better knowledge of changes in gait pattern will facilitate appropriate treatment. LBP patients adopt a walking pattern that limits the natural up and down body motion seen in normal subjects. It has been reported that patients with LBP walk more slowly, take shorter steps and do not show the symmetrical gait patterns evident in normal controls (11-13). This may be the result of dysfunction at the muscle level, decreased fine neural motor control, or muscle pain inhibiting the ability to generate force. Altered pattern of muscle recruitment has been observed in patients with LBP (14). Sacroiliac joint dysfunction can result from malrecruitment of the gluteous maximus motor unit during weight bearing, which results in compensatory biceps overactivation, soft tissue strain and joint instability, and all manifest in LBP (14). This study showed that a small difference between F2 and Fmin in the vGRF curve in patients with LBP corresponded with muscle disbalance in the pelvis and lower back. As soon as these muscles were treated with stretching and/or exercises the vGRF improved and the curve neared normal shape.

Lee et al (1) found no differences in all vGRF parameters between patients with LBP but without referred leg pain and the control group. In contrast, in this examined collective only a small number of patients had referred leg pain but the differences in the values of F2 as well as the differences between F1 and Fmin, and F2 and Fmin were highly significant.

It would be supposed that there are bilateral asymmetries during able-bodied gait, but this has only been shown at fast speed, where contributions to propulsion were greater for the dominant limb (15) and the maximum vGRF increases linearly with gait speed during walking and running (14, 16),. Most of the LBP patients in this study had an asymmetric gait pattern and walked significantly slower in painful phases than during the pain-free period at their preferred walking speed. They chose their preferred speed of walking and this was significantly higher in pain-free post-testing. Therefore, they were able to walk faster with ease.

It has been postulated that physical therapy should consider gait training as well as exercises aimed at improving intersegmental and muscle coordination (13) and this suggests that walking is a wise choice for general back exercise and rehabilitation programs (17).

The results in this study showed that changing the gain pattern of LBP patients as part of physiotherapy in the first acute painful phases could minimize or even release pain.

Conclusions

The present results point out the potential power of measuring GRF and consequential gait correction in the treatment of patients with LBP. According to these results, patients with LBP had a typical gait pattern depictured in the typical shape of the vGRF curve, and a great number of these patients could benefit simply by changing their gait pattern. Additional physical or manual medical treatment for muscle dysbalance could be required for a fixed new gait pattern.

Measurements of GRF during walking and gait analysis in patients with LBP have potential use in the evaluation, treatment planning and determination of treatment outcome.

Clinical Messages

Patients with LBP had a typical gait and a great number of these patients could benefit simply by changing their gait pattern. Systematic inclusion of gait-analysis and -correction in the rehabilitation of patients with LBP could help achieve therapeutical aims rapidly and efficiently.

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Table 1 Vertical ground reaction forces variables in patients with low back pain pre and post treatment

Variables	Pre mean (SD)	Post mean (SD)	*P*
First peak vertical ground reaction forces (F1) (kg)	77.43 (17.49)	78.08 (16.96)	0.105
Minimum at midstance (Fmin) (kg)	62.73 (14.50)	62.18 (14.71)	0.112
Second peak vertical ground reaction forces (F2) (kg)	78.55 (16.68)	80.72 (16.84)	<0.001
Speed (preferred) (kg/h)	3.616 (0.461)	3.657 (0.469)	<0.001
Cadence (stride/min)	103.2 (11.8)	105.7 (9.6)	<0.001
Time duration from beginning of stance phase to F1 (sec)	0.205 (0.038)	0.203 (0.035)	0.327
Time duration from F2 to the end of stance phase (sec)	0.205 (0.038)	0.203 (0.035)	0.368
Difference between F1 and F2 (kg)	1.11 (8.01)	2.63 (6.04)	0.001
Difference between F1 and Fmin (kg)	14.67 (8.29)	15.84 (7.32)	0.015
Difference between F2 and Fmin (kg)	15.73 (7.53)	18.27 (7.83)	<0.001

Figure legends

Figure 1a. vGRF curve of a 60-year-old male patient with LBP before treatment in painful phases

Figure 1b. vGRF curve of the same patient with LBP after treatment in pain-free phases

Figure 2a. vGRF curve of a 35-year-old patient with LBP before treatment in painful phases

Figure 2b. vGRF curve of the same patient with LBP after treatment in pain-free phases

F1 – first peak of vGRF, after heel contact the center of mass accelerated upwards reaching the maximum within seconds.

Fmin – minimum of vGRF, achieved in the moment when the center of mass is accelerated downwards

F2 – second peak of vGRF, during push-off, when the center of mass accelerated again upwards reaching the second maximum of vGRF.

Time F1 – time duration from beginning of stance phase to first peak of vGRF

Time F2 – time duration from second peak of vGRF and the end of stance phase

F1 – Fmin – differences between first peak and minimum of vGRF

F2 – Fmin - differences between second peak and minimum of vGRF

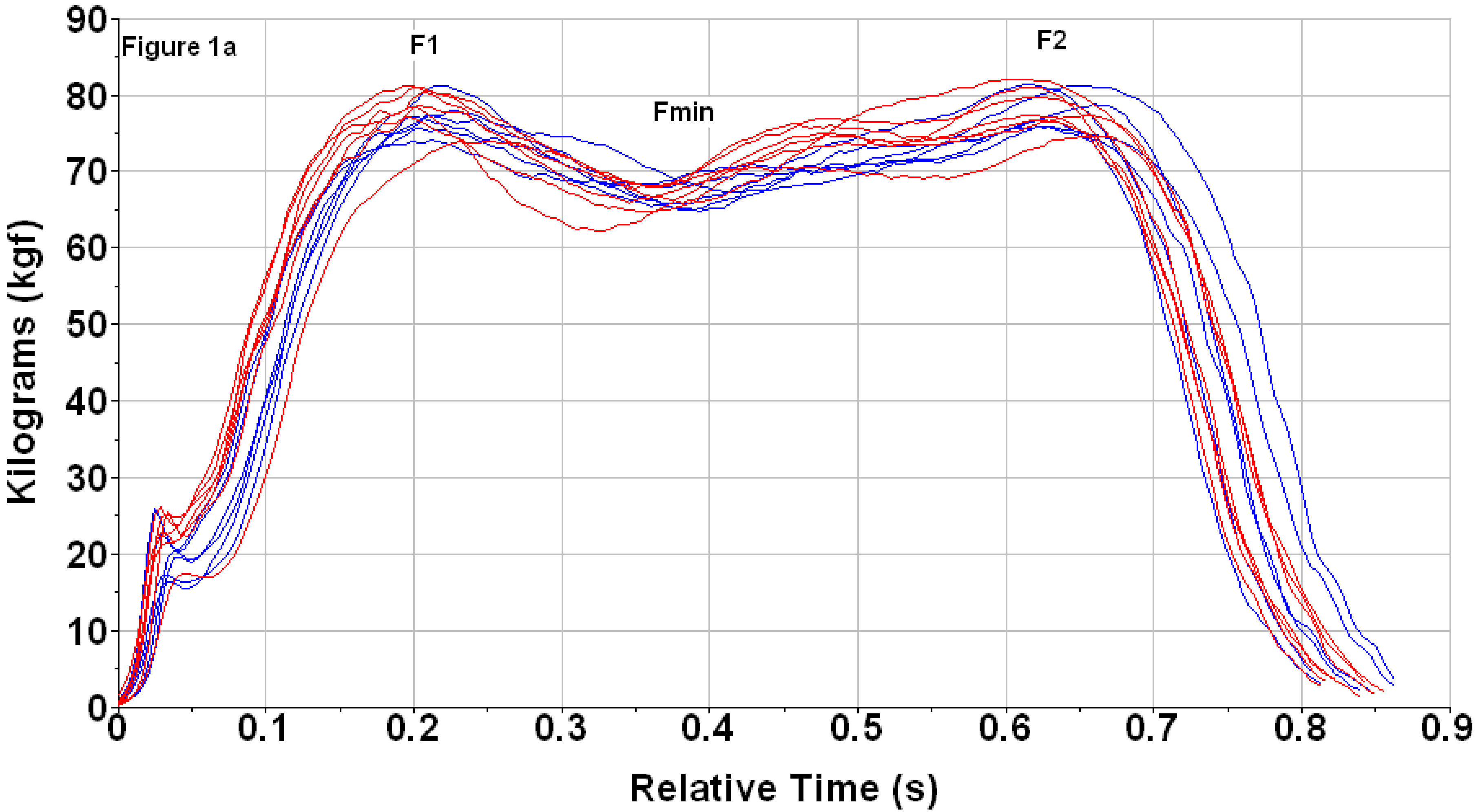
Figure 1a
F1
Fmin
F2
Kilograms (kgf)
Relative Time (s)
0
10
20
30
40
50
60
70
80
90
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9

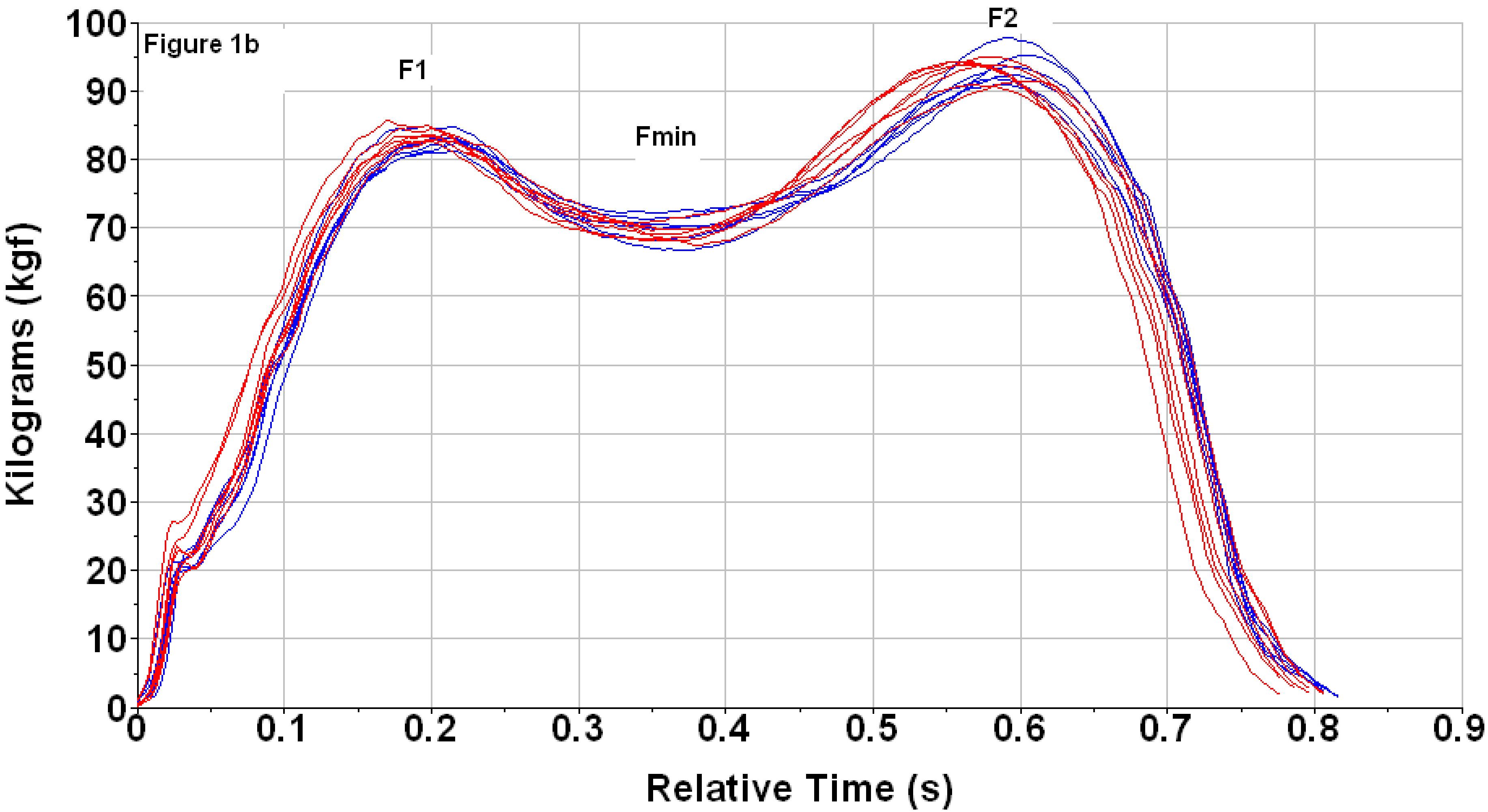
Figure 1b
F1
Fmin
F2
Kilograms (kgf)
Relative Time (s)
100
90
80
70
60
50
40
30
20
10
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9

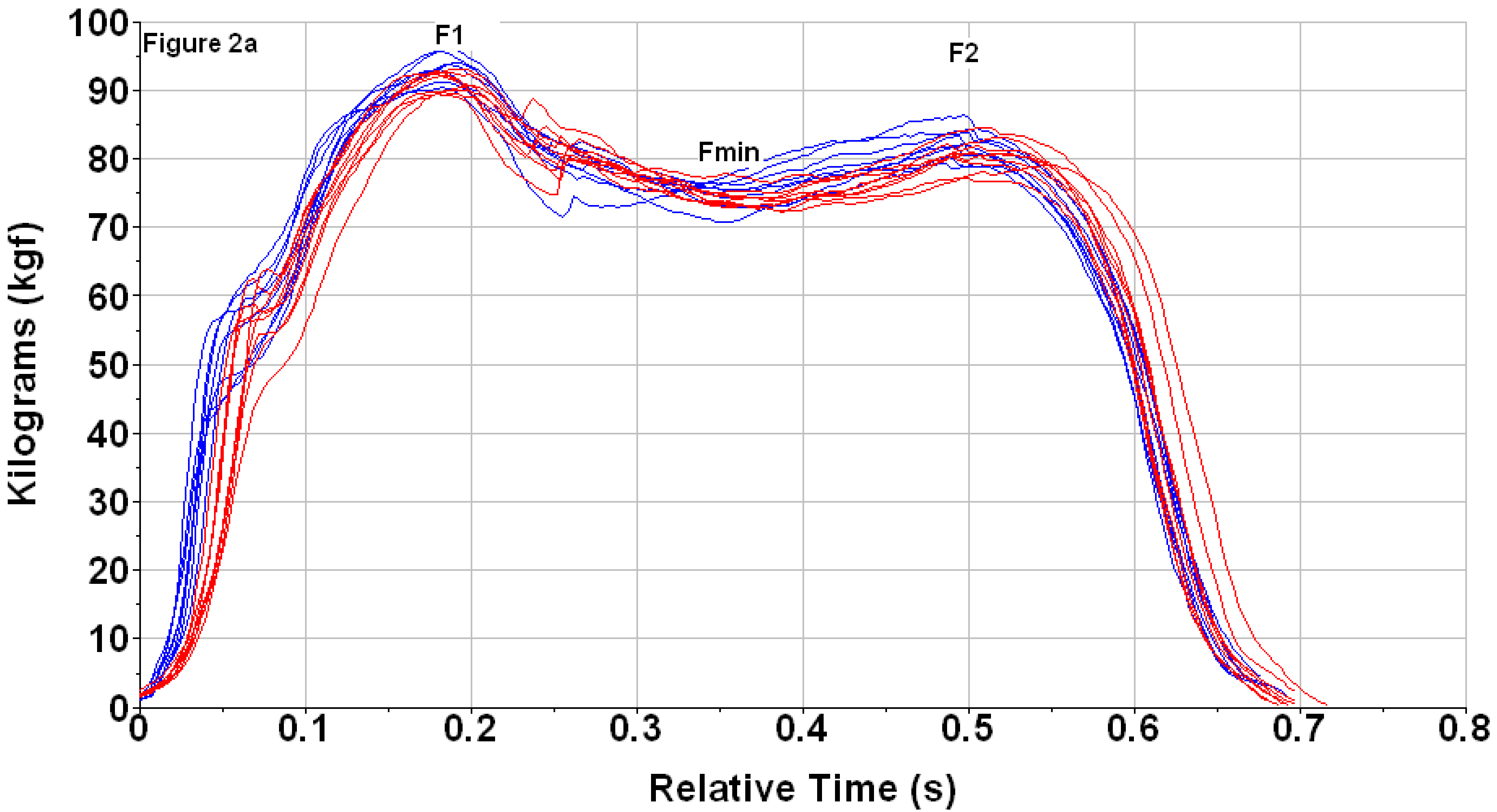
Figure 2a
F1
F2
Fmin
100
90
80
70
60
50
40
30
20
10
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
Kilograms (kgf)
Relative Time (s)

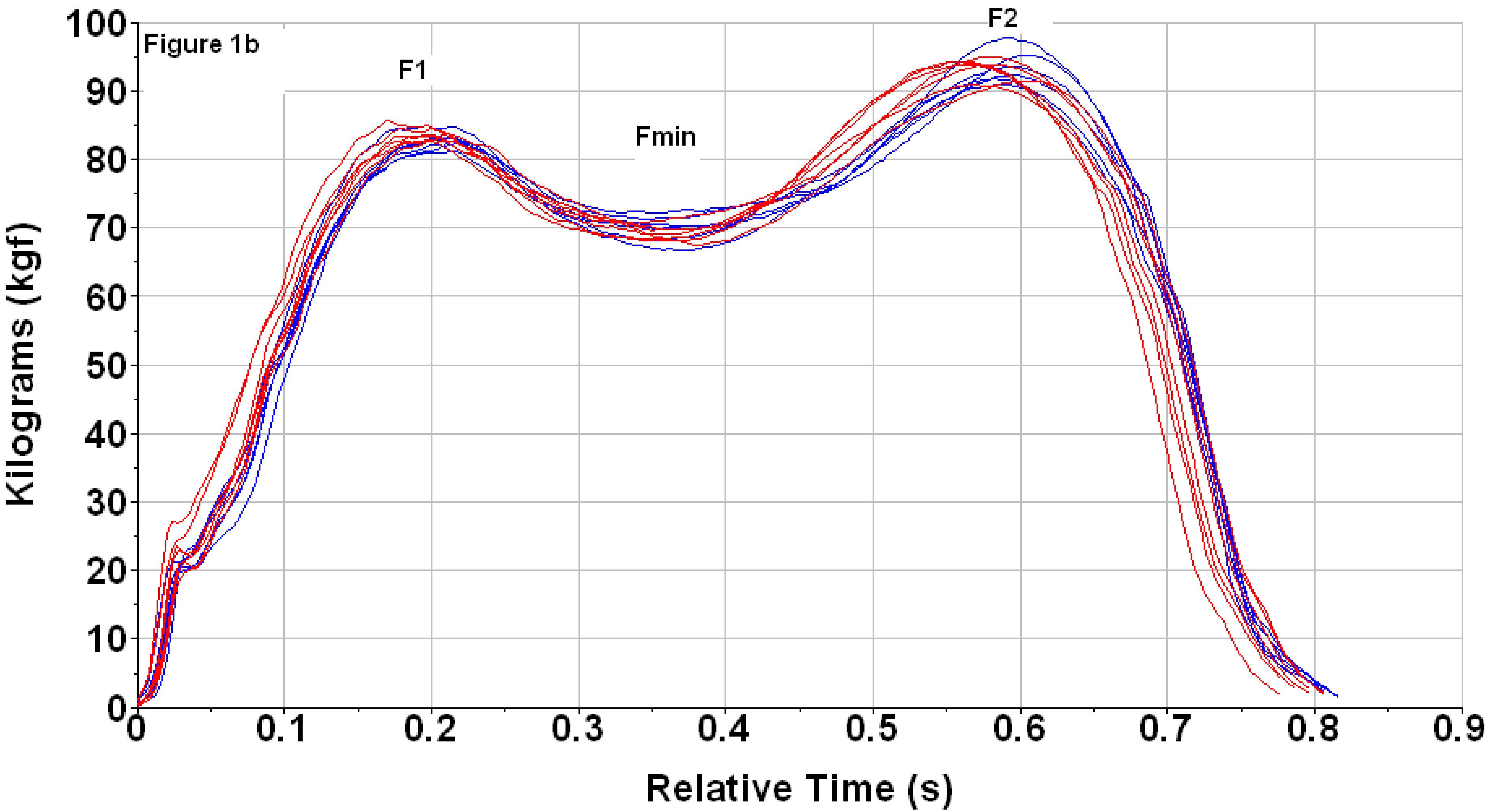

Figure 1b
F1
Fmin
F2
Kilograms (kgf)
100
90
80
70
60
50
40
30
20
10
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
Relative Time (s)