Pedaling asymmetry in unilateral transtibial amputee cyclists and the effect of prosthetic foot stiffness

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Introduction

- Provides cardiovascular exercise
- Sport applications
- Rehabilitation Potential
- Prosthetic design for cycling can be aided by an understanding of the forces involved

Introduction

- No peer reviewed articles on amputee cycling
- Basic analysis of how an amputee produces power during cycling must be complete before a rehabilitation protocol or prosthetic design can be undertaken
- Quantifying the asymmetry in power and force production of amputee cyclists is the first step

Purpose

- Quantify the contribution of each leg to power production, the difference being pedaling asymmetry
- Determine the effect of prosthetic foot stiffness
- Examine differences to the intact population

Hypotheses

1) Pedaling asymmetry in the amputee group will be greater than the intact group
2) The amputee will depend more on their sound limb for power
3) Asymmetry will decrease as the prosthetic foot stiffness increases

Methods

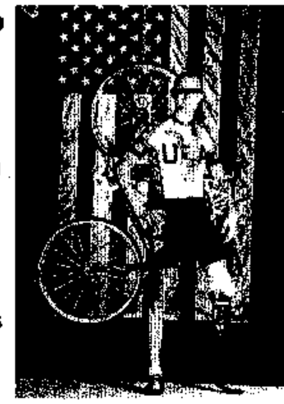
- Two Groups
  - Amputee Group
  - Control Group (intact cyclists)
- IRB approval
- Written informed consent
- Amputee group compensated

Amputee Group Criteria

- Unilateral transtibial amputees with cycling experience
- One year post amputation
- Ride at least once per month
- Not be related to a vascular condition
- No cardiovascular or neurological impairments
- Between ages of 18 - 70

Amputee Group Data

- 8 Subjects recruited
- 7 Males, 1 Female
- Cycling experience ranged from recreational to competitive
- 6 w/ left leg amputated
- 2 w/ right leg amputated
- Body Mass (kg) = 83.2, SD= 13.5
- Age (yrs) = 39.5, SD=13.6



Intact Group Criteria

- Intact persons (non-amputees) with cycling experience
- Ride at least once per month
- No cardiovascular or neurological impairments
- Between ages of 18 - 70

Intact Group Data

- 9 Subjects recruited
- 8 Males, 1 Female
- Cycling experience ranges from recreational to competitive
- Body Mass (kg) = 74.5, SD= 6.5
- Age (yrs) = 40.4, SD=13.4

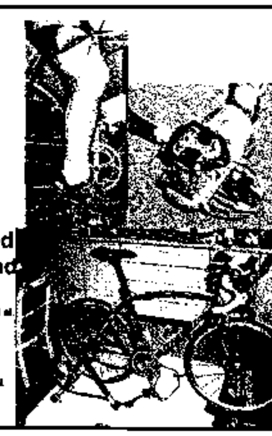
Definition of Variables

- Work Asymmetry
  - Difference in the contribution of each leg to total work
  - Expressed as a percent
  - Can show differences in each leg's ability to direct force on the pedal
- Force Asymmetry - Sanderson
  - Difference in the contribution of each leg to the total force used to pedal
  - Expressed as a percent
  - Can show weaknesses between legs

- Sanderson

Equipment

- Subjects cycled their personal bicycle mounted in a stationary trainer
- Dual piezoelectric force pedals measured force in the normal and tangential directions - Broker, et al
- Potentiometers measure pedal and crank position - Broker, et al



Prosthesis

- Prosthetic feet included a dynamic response type foot (DR foot) and a non-flexible aluminum plate foot (AL foot)
- DR foot stiffness based on subject body mass
- Subject used their own socket
- Length and alignment of prosthesis was duplicated

Prosthesis

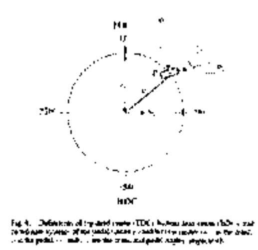
- Cycling cleat location mounted at the 1st metatarsal head
- Cycling cleat was screwed directly into the toe section of the foot.
- No foot shell and no heel section
- Prosthetic modifications preformed by Certified Prothetist

Data Collection Protocol

- Pedal at a self selected "easy pace", "hard pace" (resistance and cadence)
- Foot order randomized
- Trial order was randomized within foot order
- Subjects start with a warm up at an easy pace for 5 minutes
- Each load condition lasted 6 minutes with data collected over the last one minute

Data Reduction

- Averaged five cycles
- Force data reduced into components perpendicular to the crank (effective force) and longitudinal to the crank (ineffective force)
- Torque about the crank spindle was calculated
- Torque integrated with angular velocity of the crank to calculate power

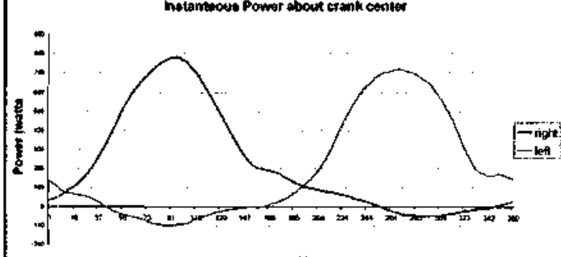


- Adapted from Prilutsky et al

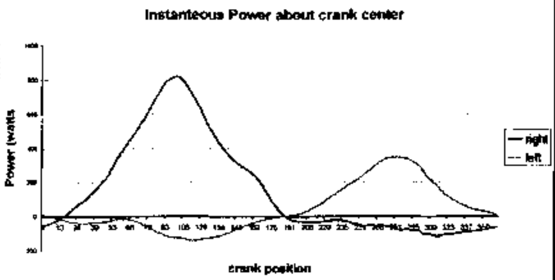
Statistical Analysis

- Two Tailed Paired T-test used to compare differences in prosthetic feet
- Two Tailed Independent T-test used to compare differences between amputee and intact groups

Exemplar Data – Intact Group



Exemplar Data – Amputee Group



Results – "Hard" Pace

	%Work Asym	SD	%Force Asym	SD
Amputee, DR Foot	28.5*	12.8	12.3*	9.6
Amputee, AL Foot	29.9*	9.2	10.9*	4.6
Intact	5.4	3.4	5.1	2.9

* Indicates significant difference $p = 0.05$ with intact group

Summary of results

1) Pedaling asymmetry in the amputee group was greater than the intact group ✓
2) The amputee did depend more on their sound limb for power ✓
3) Asymmetry did not change as the prosthetic foot stiffness increases

Conclusion

- Amputees have significantly more pedaling asymmetry than the intact population
- Factors creating pedaling asymmetry
  - Strength imbalance between limbs
  - Difficulty in directing forces effectively with prosthesis
  - Sound side overcompensation at the top and bottom of the pedal stroke
- Stiffness of the prosthetic foot no effect on asymmetry
- More research is necessary, particularly on the *influence of lower limb inertia* to asymmetry

References

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Supporters of Our research

- Ossur corp.
- Prosthetic Design Inc.
- Cycles
- Outback Bicycles
- 55Nine Performance

Amputee Group n=8

Amputee info	Mean	Std Dev	Min	Max
Body Weight (kg)	83.2	13.5	70	109
Age (yrs)	39.5	14.6	23	65
Height (m)	1.75	0.09	1.62	1.85

Intact Group n=9

Amputee info	Mean	Std Dev	Min	Max
Body Weight (kg)	74.5	6.5	67	86
Age (yrs)	40.4	13.4	27	67
Height (m)	1.81	0.06	1.70	1.88

Results – "Easy" Pace

	%Work Asym	SD	%Force Asym	SD
Amputee, DR Foot	42.8*	39.5	9.8*	6.5
Amputee, AL Foot	49.2*	30.3	11.6*	6.7
Intact	9.2	8.0	5.5	3.5

* Indicates significant difference $p = 0.05$ with intact group

Results - Hard

	Wattage	SD	Cadence	SD	% max HR	SD
Amputee, DR Foot	216	95	84	19	81	15
Amputee, AL Foot	212	85	84	14	87	10
Intact	304	90	97	12	91	4

Results - Easy

	Wattage	SD	Cadence	SD	% max HR	SD
Amputee, DR Foot	87	49	75	16	69	16
Amputee, AL Foot	79	50	71	13	68	12
Intact	137	52	90	8	68	6

Results - Thigh circumferences

	% difference	SD
Amputee	8.9*	4.4
Intact	1.4	0.9

* Indicates significant difference $p = 0.05$ with intact group

Results – Cycling Habits

	Cycling freq (hrs/mon)	SD	Cycling exp (yrs)	SD
Amputee	32.8	24.1	8.6	12.3
Intact	34.8	19.4	15.3	14.8

Results – Easy Pace

Subject Number	Dominant Side	Amputated Side
1	Right	Right
2	Right	Right
3	Left	Left
4	Right	Right
5	Right	Right
6	Right	Right
7	Left	Left
8	Right	Right