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Title:	Medicine and science in sports
Title Abbrev:	Med Sci Sports
Citation:	1979 Winter;11(4):328-31
Article:	Functional variability of the lower extremity during the sup
Author:	Bates BT;Osternig LR;Mason BR;James SL
NLM Unique ID:	0203246 Verify: PubMed
PubMed UI:	530023
ISSN:	0025-7990 (Print)
Fill from:	**Any format**
Publisher:	American College of Sports Medicine., [Madison, Wis.]
Copyright:	Copyright Compliance Guidelines
Authorization:	Geri Bodeker
Need By:	N/A
Maximum Cost:	**Free**
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MEDICINE AND SCIENCE IN SPORTS
Vol. 11, No. 4, pp. 328-331, 1979

Functional variability of the lower extremity during the support phase of running

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ABSTRACT

BATES, B.T., L.R. OSTERNIG, B.R. MASON, and S.L. JAMES. Functional variability of the lower extremity during the support phase of running. *Med. Sci. Sports.* Vol. 11, No. 4, pp. 328-331, 1979. The purpose of the research was to determine the variability of selected parameters during the support phase of running between consecutive right footfalls, and the included left footfall, as well as to acquire additional descriptive data on lower extremity function. Eleven college aged male runners were filmed (200 fps) from the rear and side while running on a treadmill at 4.29-4.47 m/sec. The statistical analysis of the mean absolute differences for temporal events between the three footfalls resulted in no significant differences. An estimate of event variability was calculated to be the actual time ± 0.0110 sec or the percentage ± 4.98% at the 95% confidence interval. Comparisons between the absolute deviations of selected body part positions and/or orientations for the test conditions resulted in no statistically significant differences. Estimates of variability ranging from 1.78-4.08 deg were calculated. Even though no statistically significant differences were obtained, the magnitude of the variability obtained for the parameters evaluated would seem to indicate a need for calculating representative or average values if subtle differences in lower extremity function are to be detected.

PRONATION/SUPINATION, DESCRIPTIVE LEG MOVEMENT, TREADMILL

A large proportion of today's population is aware of the benefits to be gained from being physically fit, and a considerable number of individuals rely on jogging as a means to acquire and retain their fitness. Many cardiac rehabilitation clinics utilize jogging in their recovery programs for post coronary patients. This increased interest in running has resulted in more people accruing greater mileage. With this increase in the number of joggers and/or mileage run there has been a corresponding rise in the number of foot and leg problems.

Although a number of factors must be considered in the diagnosis of lower extremity problems encountered by runners, it appears as though many of the problems are associated, either directly or indirectly, with foot structure and/or function during the support phase of the activity (2,3). Before establishing the mechanisms which lead to specific leg and foot problems, it is necessary to identify and determine the relationships between selected parameters associated with normal running gait.

Submitted for publication August, 1978.
Accepted for publication August, 1979.

This study is one of a series of investigations being conducted to gain greater insight into the dynamic functioning of selected lower extremity components which may have clinical significance in the treatment of running injuries. The purpose of this research was to determine the variability of selected temporal events and associated kinematic parameters between consecutive footfalls as well as to acquire additional descriptive data on lower extremity function.

PROCEDURES

Eleven college aged male runners running in excess of 25 miles per week and experiencing no leg or foot problems served as subjects. They were filmed while running on a treadmill using two high speed super 8 mm cameras (Visual Instrumentation Corporation, Model SP-1) operating at 198-206 frames/second. Films were obtained of the lower leg and foot from the rear and the entire lower extremity from the lateral view. A one second sweep clock (marked in .01 sec intervals) located within the photographic field was utilized to obtain camera speeds and to synchronize the two views. All subjects wore running shorts and the same type of shoe (Nike Boston) for testing.

The runners were filmed while running on a treadmill at speeds of 4.47 m sec (6 min mile pace) or 4.29 m sec (6:15 min mile pace). The speeds were calculated on the basis of each runner's best previous performance so that all runners were running at the same relative speed. The treadmill was chosen instead of over-ground running to ensure consistency of foot placement and running velocity as well as to obtain several consecutive footfalls with a minimum of perspective error. To minimize differences that might exist between treadmill and overground running, all subjects participated in three one-half hour supervised training sessions prior to being filmed.

The intermediate positions previously defined by Bates et al. (1) were used to divide the support period into discrete phases. The following definitions are given to clarify terms and define selected events or positions:

Pronation—Eversion of the calcaneous relative to the midline of the leg. Measurement used to approximate the true action of pronation.

Supination—Inversion of the calcaneous relative to the midline of the leg. Measurement used to approximate the true action of supination.

Begin Pronation—Neutral position attained by the calcaneous relative to the leg when moving from a supinated to a pronated position.

Maximum Pronation—Position of greatest eversion of the calcaneous relative to the leg.

End Pronation—Neutral position attained by the calcaneous relative to the leg when moving from a pronated to a supinated position.

Patella Cross—Position in which the patellas of both legs are in line with the lateral camera axis. Position used to approximate center-of-gravity passing over base of support.

The terms begin pronation, maximum pronation and end pronation are used in this paper to identify positions so that distinctions can be made between when the joint is in a pronated or supinated position. The action of pronation terminates when the position of maximum pronation is reached and is followed by the action of supination.

The films were evaluated using a Lafayette Super 8 Analyzer in conjunction with a Numonics Graphics Digitizer interfaced to a Tektronix 4051 Graphics Calculator. The data were analyzed in two categories: (1) temporal evaluation of selected critical events throughout the support phase, and (2) kinematic analysis of selected body parts at the occurrence of the selected events. Three consecutive footfalls (test conditions) in a right-left-right sequence were evaluated. Means and standard deviations were computed for all data sets. In addition, absolute and relative values as well as the absolute differences between individual items were analyzed using a one-way analysis of variance design with repeated measures. Planned comparisons were conducted between the three conditions in addition to the absolute differences between the conditions, $F\ (1,\ 10) = 4.96\ p < .05$. Individual parameters at the three positions of maximum knee flexion, patella cross, and maximum pronation were analyzed using a two-way analysis of variance, with repeated measures across both variables $F\,(2, 20) = 3.49, p < .05$.

RESULTS AND DISCUSSION

The data describing the occurrence of selected events are presented in Table 1. Values are given in both absolute time and as a percentage of the support period. The comparison between the various conditions for the different events showed only one significant comparison indicating that the relative efforts (i.e. running at a fixed percent of maximum) of all runners produced similar results. No differences were found to exist between the events of maximum pronation, maximum knee flexion, and patella cross. This result is in agreement with previous results reported by Bates et al. (1).

The relationship between pronation/supination and knee flexion/extension is important since an obligatory tibial rotation is associated with the actions of both of these joints. Pronation and knee flexion are both accompanied by internal tibial rotation while supination and knee extension both result in external rotation. It therefore becomes very critical, especially for people doing a lot of running, that these joint activities be synchronous and complimentary. If maximum pronation and maximum knee flexion do not occur at the same time then the two joints will be functionally antagonistic. If this antagonistic period is prolonged, irritations may result in one of the joints.

In order to assess the differences in the occurrence of the events between the three test conditions, the absolute differences between the conditions were examined. The mean absolute differences are given in Table 2. The statistical analysis resulted in no significant differences. Since none of these comparisons were significant, a grand mean of the deviations for each event was computed and these

TABLE 1. Mean absolute and relative values of selected events occurring during the support phase of running (n=11)[a].

Event	R1		R2		L1	
	(sec)	(%)	(sec)	(%)	(sec)	(%)
Foot Strike	.0000 (.0000)	0.00 (0.00)	.0000 (.0000)	0.00 (0.00)	.0000 (.0000)	0.00 (0.00)
Begin Pronation	.0197 (.0128)	9.70 (6.22)	.0189 (.0138)	9.28 (6.79)	.0176 (.0127)	8.69 (6.25)
Maximum Pronation	.0745 (.0177)	35.97 (8.14)	.0714 (.0160)	34.28 (6.42)	.0692 (.0188)	32.92 (8.21)
Maximum Knee Flexion	.0800 (.0111)	38.85 (6.44)	.0791 (.0105)	38.25 (5.67)	.0778 (.0090)	37.18 (3.94)
Patella Cross	.0787 (.0136)	38.05 (6.32)	.0805 (.0160)	38.74 (6.95)	.0834 (.0180)	39.65 (7.39)
Maximum Ankle Dorsiflexion	.1040 (.0071)	50.25 (2.52)	.1053 (.0087)	50.70 (2.82)	.1077* (.0076)	51.36 (1.90)
End Pronation	.1641 (.0242)	79.09 (10.45)	.1562 (.0341)	75.04 (15.15)	.1697 (.0208)	80.65 (7.23)
Toe-Off	.2078 (.0087)	100.00 (0.00)	.2083 (.0085)	100.00 (0.00)	.2105 (.0107)	100.00 (0.00)

[a]Numbers in parentheses indicate standard deviations.
*R1 < L1, p < .05

TABLE 2. Mean absolute deviations between all conditions for selected events (n=11)[a].

Event	R1-R2		R1-L1		R2-L1		M[b]	
	(sec)	(%)	(sec)	(%)	(sec)	(%)	(sec)	(%)
Begin Pronation	.0068 (.0049)	3.13 (2.35)	.0083 (.0071)	4.10 (3.57)	.0120 (.0066)	5.83 (3.12)	.0090 (.0064)	4.35 (3.17)
Maximum Pronation	.0126 (.0107)	5.89 (5.09)	.0123 (.0101)	5.84 (5.16)	.0136 (.0127)	6.27 (5.46)	.0128 (.0109)	6.00 (5.08)
Maximum Knee Flexion	.0062 (.0041)	3.17 (2.79)	.0087 (.0065)	4.45 (3.55)	.0073 (.0066)	3.02 (3.38)	.0074 (.0058)	3.55 (3.22)
Patella Cross	.0065 (.0050)	3.68 (1.98)	.0101 (.0079)	4.48 (3.41)	.0087 (.0061)	4.24 (2.37)	.0084 (.0064)	3.80 (2.70)
Maximum Ankle Dorsiflexion	.0040 (.0026)	1.38 (.80)	.0054 (.0037)	2.01 (1.51)	.0041 (.0041)	1.90 (1.28)	.0045 (.0035)	1.76 (1.22)
End Pronation	.0212 (.0165)	8.67 (6.76)	.0207 (.0190)	9.42 (7.71)	.0299 (.0238)	13.40 (10.93)	.0239 (.0198)	10.50 (8.64)
Toe-Off	.0050 (.0045)	1.30 (1.06)	.0055 (.0042)	1.54 (.85)	.0041 (.0030)	1.76 (.91)	.0048 (.0038)	1.53 (0.93)
M[c]							.0101 (.0081)	4.52 (3.57)

[a]Numbers in parentheses indicate standard deviations.
[b]Means of all values for all conditions for each event.
[c]Grand mean for all conditions and events.

TABLE 3. Mean angular values describing position or orientation of selected parameters for different events.

Event	Condition R1	R2	L1
Max Pronation			
Knee	140.04 (5.16)	138.87 (3.47)	140.69 (4.30)
Ankle	97.32 (5.90)	98.27 (3.65)	99.12 (4.80)
Pronation	8.35 (3.92)	8.65 (5.02)	10.37 (3.41)
Leg	80.38* (2.12)	79.99** (1.91)	77.82* (2.18)
Heel	88.74 (3.87)	88.62+ (4.84)	88.19 (2.80)
Max Knee Flexion			
Knee	137.42 (3.95)	137.46 (4.17)	138.82 (4.23)
Max Ankle Dorsiflexion			
Ankle	92.44 (2.50)	91.66 (2.02)	91.07 (2.77)
Pronation	6.99 (4.36)	7.00 (5.64)	8.24 (3.81)

[a]Numbers in parentheses indicate standard deviations.
*R1>L1 and R1-R2 ≠ R1-L1, $p < .05$
**R2>L1 and R1-R2 ≠ R2-L1, $p < .05$
+R1-R2 ≠ R2-L1, $p < .05$

values are also presented in Table 2. The values indicate both the absolute and relative variability that occurred for each event between the three footfalls. The greatest variability was found to occur for the events of maximum pronation and end pronation. An overall mean estimate for the occurrence of an event was the actual time ± 0.0110 sec or the percentage ± 4.98% at the 95 confidence interval.

Table 3 gives the mean angular position or orientation values of various body parts for selected events. Five significant differences were found with four of them pertaining to the relationship between the right and left leg. Since leg orientation is a component of pronation, these differences are partially reflected in the values of maximum pronation. Even though no significant differences were observed for pronation values the larger values for Ll probably are at least part of the reason for the greatest variability being observed for the events of maximum pronation and end pronation.

The comparisons for the absolute deviations between test conditions for the identified events showed no statistically significant differences. The variability for each body part was determined for each event and a grand mean calculated to give an overall estimate of variability through the support phase (Table 4). The 95% confidence intervals were also computed and are shown in Table 4.

The descriptive data obtained in this study were quite similar to those previously reported by Bates and associates (1978). Table 5 contains the grand mean values for all 33 footfalls in this study and the mean values for the fast-shoe condition from the previous study. The greatest differences occurred at begin and end pronation. The mean period of pronation occupied 69.04% of the support period compared to only 53.97% for the women. This could have been due in part to the faster average running speed of the men since it was previously shown that increases in running speed resulted in increased periods of pronation (1). Kinematic parameters determined in the previous study were mean values of 145.0 deg of knee flexion, 101.5 deg of ankle dorsiflexion and 8.6 deg of pronation obtained from a varus leg and slightly valgus heel orientation of 81.6 and 90.2 deg, respectively at maximum pronation. Maximum knee flexion and ankle dorsiflexion were 143.1 and 100.5 deg, respectively. The differences between these values and those given in Table 4 could logically be the result of the speed differences or they could also be the result of actual "structural" anatomical differences.

Even though no statistically significant differences between the body parameters and conditions were obtained,

TABLE 4. Mean absolute deviations between all test conditions for selected parameters (n=11)[a].

Event	Knee	Ankle	Pron	Leg	Heel
Foot Strike	2.60	2.65	4.47	1.57	2.74
	(2.54)	(2.82)	(6.43)	(1.42)	(2.46)
Begin Pronation	3.73	3.52	0.00	1.70	1.99
	(3.11)	(2.18)	(0.00)	(1.71)	(2.12)
Maximum Pronation	2.47	3.56	2.22	1.93	1.95
	(2.25)	(2.74)	(2.29)	(1.64)	(1.55)
Maximum Knee Flexion	2.73	2.81	1.97	1.77	2.00
	(2.43)	(1.85)	(1.74)	(1.47)	(1.47)
Patella Cross	2.36	2.55	2.00	2.24	1.88
	(2.24)	(1.74)	(1.73)	(2.57)	(1.55)
Maximum Ankle Dorsiflexion	3.48	2.38	2.31	1.75	2.14
	(3.07)	(1.70)	(1.88)	(1.53)	(1.56)
End Pronation	7.36	11.26	0.00	1.68	1.69
	(6.01)	(9.51)	(0.00)	(1.50)	(1.48)
Toe-Off	2.56	3.94	5.27	1.59	5.62
	(2.17)	(3.88)	(3.98)	(1.67)	(3.74)
M	3.41	4.08	3.04	1.78	2.50
	(2.98)	(3.30)	(3.01)	(1.69)	(1.99)
95% Confidence Interval	±3.79	±4.51	±3.43	±2.00	±2.76

[a]Numbers in parentheses indicate standard deviations.

TABLE 5. Grand mean values for all events for two groups[a].

	4.29-4.47 m/sec[b] n=33 foot-falls		3.83-4.47 m/sec[c] n=10 foot-falls	
Event	(sec)	(%)	(sec)	(%)
Foot Strike	.0000	0.00	.0000	0.00
	(.0000)	(0.00)	(.0000)	(0.00)
Begin Pronation	.0188	9.22	.0318	15.06
	(.0127)	(6.24)	(.0106)	(4.88)
Maximum Pronation	.0717	34.39	.0821	38.58
	(.0171)	(7.50)	(.0117)	(3.35)
Maximum Knee Flexion	.0790	38.09	.0855	40.40
	(.0100)	(5.32)	(.0075)	(3.76)
Patella Cross	.0808	38.81	.0847	39.41
	(.0156)	(6.71)	(.0119)	(3.71)
Maximum Ankle Dorsiflexion	.1057	50.77	.1088	51.15
	(.0078)	(2.41)	(.0112)	(1.77)
End Pronation	.1633	78.26	.1467	69.03
	(.0267)	(11.31)	(.0207)	(7.58)
Toe-Off	.2089	100.00	.2124	100.00
	(.0092)	(0.00)	(.0175)	(0.00)

[a]Numbers in parentheses indicate standard deviations.
[b]Means of all values for all conditions.
[c]Data from Bates, B.T., et al. (1978).

it was evident that there was some variability between footfalls on all parameters evaluated. The magnitude of this variability would seem to indicate a need for calculating representative or average values if subtle differences in lower extremity function are to be detected. For example, comparisons between the effects of two different shoes on the dynamic functioning of the leg would probably require the composite evaluation of several footfalls since the effects of shoes appear to be quite subtle.

Research supported in part by a grant from the Northwest Area Foundation.

S.L. James is at the Orthopedic and Fracture Clinic of Eugene.

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