MATHEUS OLIVEIRA DE ALMEIDA

DISTRIBUIÇÃO E CARACTERIZAÇÃO DO PADRÃO DE ATERRISSAGEM DO PÉ NO SOLO EM CORREDORES

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Dissertação apresentada ao Programa de Mestrado em Fisioterapia da Universidade Cidade de São Paulo, como requisito exigido para obtenção do título de Mestre sob orientação do Prof. Dr. Alexandre Dias Lopes.

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CONTEXTUALIZAÇÃO

1.1 INTRODUÇÃO

A corrida é um dos esportes mais populares no mundo[1], e no Brasil o número de praticantes vem crescendo significantemente nos últimos anos. Estima-se que atualmente cerca de 5% da população brasileira, aproximadamente 10 milhões de indivíduos, pratique a corrida como atividade física[2]. Grande parte dos adeptos da corrida busca uma melhor qualidade de vida, além da prevenção de diversas doenças sistêmicas, por meio de um maior controle do peso corporal e da capacidade cardiovascular, além da facilidade e o baixo custo que envolve a prática desse esporte.

Com aumento do número de praticantes de corrida houve um aumento proporcional do número de lesões musculoesqueléticas, com taxas de incidência e/ou prevalência que variam entre 19% e 79%[3-8]. Muitos estudos têm investigado fatores predisponentes para as lesões musculoesqueléticas relacionadas à corrida, mas os resultados dos estudos demonstram não haver evidências suficientes que a maioria dos fatores pesquisados, como o tipo de superfície utilizada, fatores anatômicos e padrão de pisada sejam fatores de risco para a corrida[1, 8-16].

Diante da ausência de evidência de fatores que expliquem o grande número de lesões na corrida, uma atenção especial vem sendo dada para a parte do pé que toca primeiramente no solo, já que o pé é a parte do corpo que recebe diretamente as forças do solo[17]. Talvez a adoção de determinadas estratégias de aterrissagem do pé no solo possa ser responsável por uma maior proteção do sistema musculoesquelético contra lesões[18].

Existem diferentes definições para a classificação do padrão de aterrissagem do pé durante a corrida. A definição mais utilizada e que parece ser a mais adequada, classifica os padrões da seguinte forma: (1) retropé, quando o contato inicial é realizado com a parte posterior do pé; (2) mediopé, quando a parte anterior e posterior do pé tocam simultaneamente no solo; e (3) antepé, quando a parte anterior do pé toca antes da parte posterior no solo[18]. Quando o indivíduo realiza a aterrissagem com o retropé ele provoca dois picos de impacto verticais desde o momento do contato inicial até o momento do desprendimento do pé. O primeiro impacto, também conhecido como primeiro pico de impacto passivo ou impacto transiente, que são forças abruptas de alta magnitude transferidas para o corpo através do contato do calcanhar com o solo, e que parece contribuir para o aparecimento de lesões musculoesqueléticas na corrida[18]. Os corredores que possuem padrão de mediopé ou antepé apresentam uma curva de impacto transiente muito pequena ou inexistente, realizando um aumento gradativo e uniforme das forças de reação do solo verticais no momento do impacto com o solo[18, 19].

Apesar da importância de se conhecer a distribuição o padrão de aterrissagem do pé no solo nos corredores, apenas três estudos são encontrados na literatura sobre o tema[17, 20, 21], sendo que o primeiro estudo que foi realizado em 1983[20] encontrou que aproximadamente 80% dos corredores pertencentes a uma prova de 10 km e uma maratona apresentaram o padrão de retropé. O segundo estudo realizado em 2007[17] também avaliou meios-maratonistas de elite e o padrão de retropé também foi o mais comum (75% dos corredores) entre os participantes. O terceiro estudo[21] também realizado durante uma prova de rua encontrou que 88% dos corredores apresentaram o padrão de retropé. Porém, esses três estudos avaliaram apenas maratonistas de elite e corredores recreacionais participantes de provas, comprometendo qualquer inferência aos corredores que não possuem esse perfil.

A metodologia utilizada pelos três estudos[17, 20, 21] para avaliar o padrão de aterrissagem foi feita através da análise de imagens por vídeo. A precisão da avaliação do padrão de aterrissagem do pé no solo está diretamente relacionada com o aumento da frequência de aquisição de imagens[22], e quando a frequência de aquisição utilizada é inadequada, como a utilizada pelos estudos do Kerr et al[20] e Hasegawa et al[17], pode levar a uma classificação equivocada principalmente entre os corredores com padrão de retropé, que podem ser classificados erroneamente como mediopé.

Durante muito tempo o padrão de retropé, ou seja, contato inicial sendo feito com o calcanhar, foi adotado como a maneira “mais apropriada” para a corrida recreacional de longa distância, ao ponto que profissionais da área adotaram o termo “correr certo” para aqueles que possuem esse padrão, mesmo não havendo evidência que suportem esse raciocínio. Acredita-se que a maioria dos praticantes de corrida realize a aterrissagem do pé no solo com o retropé provavelmente devido à evolução dos calçados esportivos ao longo do tempo que aumentaram a espessura e o amortecimento na região do retropé facilitando o contato inicial do pé no solo nesta região, e ainda influenciado por esta crença de que tocar o solo inicialmente com o calcanhar seria a maneira correta para correr[18].

Praticamente todos os estudos existentes na literatura sobre calçado para corrida e biomecânica da corrida (pronação, supinação do pé, angulação de tornozelo e joelho durante contato inicial) são baseados apenas em corredores que possuem o padrão de aterrissagem com o retropé[23-25]. Porém, recentemente alguns estudos têm proposto que o padrão de aterrissagem feito com parte anterior do pé ou médiopé parece ser o padrão mais natural de corrida e que esse padrão poderia atenuar as forças de impacto[17, 18, 26-29], não estando de acordo com a orientação atual da maioria dos profissionais em relação à técnica adequada da corrida e a tendência da indústria de calçados de corrida ao longo dos anos.

Desta forma os objetivos dessa dissertação foram: 1) revisar na literatura as características biomecânicas relacionadas aos tipos de padrões de aterrissagem no solo durante a corrida; 2) verificar a distribuição dos três tipos de padrões de aterrissagem do pé no solo entre a população de corredores em geral; 3) comparar as características pessoais e de treinamento entre os padrões de aterrissagem adotados pelos corredores.

1.2 APRESENTAÇÃO DOS ESTUDOS ENVOLVIDOS NA DISSERTAÇÃO

O capítulo 2 desta dissertação apresenta uma revisão sistemática que tem o objetivo de avaliar o que há de evidência na literatura sobre os aspectos biomecânicos relacionados aos três padrões de aterrissagem do pé no solo. Trata-se de um estudo pioneiro neste tema, já que até o momento não foram encontradas revisões sistemáticas que abordem os diferentes aspectos relacionados às estratégias de aterrissagem do pé durante a corrida.

O capítulo 3 trata-se de um estudo piloto, que avaliou o padrão de aterrissagem do pé no solo de 53 corredores recreacionais. A realização deste estudo foi importante para subsidiar o cálculo amostral do estudo realizado no capítulo 4, além de propiciar aos pesquisadores envolvidos um contato prévio com a metodologia que foi utilizada neste estudo, visando minimizar possíveis erros durante a coleta e aquisição das imagens.

O capítulo 4 foi um estudo realizado com 514 corredores recreacionais avaliados nos principais locais de prática de corrida da cidade de São Paulo. O estudo teve como o objetivo de verificar a distribuição do padrão de aterrissagem do pé no solo durante a corrida, além de realizar uma comparação quanto às características pessoais e de treinamento entre os padrões de aterrissagem adotados pelos corredores.

O capítulo 5 apresenta as considerações finais da dissertação, enfatizando e discutindo os principais resultados encontrados nos estudos relacionados a esta dissertação, além de abordar o impacto e importância destes resultados, e implicações para futuras pesquisas.

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-CAPÍTULO 2-

CARACTERÍSTICAS BIOMECÂNICAS RELACIONADAS AOS PADRÕES DE ATERRISSAGEM DO PÉ DURANTE A CORRIDA: UMA REVISÃO SISTEMÁTICA

(EM PREPARAÇÃO PARA SUBMISSÃO)

CARACTERÍSTICAS BIOMECÂNICAS RELACIONADAS AOS PADRÕES DE ATERRISSAGEM DO PÉ DURANTE A CORRIDA: UMA REVISÃO SISTEMÁTICA

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2.1 RESUMO

Introdução: A adoção de determinadas estratégias de aterrissagem durante a corrida pode estar associada com as lesões relacionada a esse esporte. Porém, até o momento não existem revisões sistemáticas que abordem os diferentes aspectos relacionados aos padrões de aterrissagem durante a corrida. **Objetivo:** Revisar na literatura as características biomecânicas relacionadas aos tipos de padrões de aterrissagem no solo durante a corrida. **Métodos:** Foi realizada uma busca nas principais bases de dados até novembro de 2011 dos estudos que compararam características biomecânicas entre os tipos de padrões de aterrissagem no solo durante a corrida. A avaliação do risco de viés dos estudos incluídos foi realizada através de uma escala de análise metodológica que contém itens em relação à amostra do estudo, mensuração e avaliação dos desfechos e a forma em que foi realizada a avaliação dos participantes do estudo. **Resultados:** Os resultados da busca identificaram um total de 1648 artigos, sendo que apenas 12 artigos foram incluídos nessa revisão. A avaliação do risco de viés dos estudos incluídos demonstrou uma pontuação baixa. Foram encontradas características biomecânicas diferentes entre o padrão de retropé em relação ao padrão de mediopé e antepé para as variáveis espaços-temporais (tempo de contato maior no padrão de retropé), cinemáticas (padrão de retropé com contato em inicial em dorsiflexão, maior pico de eversão e menor inversão, e uma menor velocidade de eversão) e cinéticas (impacto inicial menor no padrão mediopé e antepé). **Conclusão:** Esta revisão sistemática demonstra que os padrões de aterrissagem do pé no solo apresentaram características espaços-temporais, cinemáticas e cinéticas diferentes durante a corrida, sendo que o padrão de retropé devido ao contato inicial na posição de dorsiflexão apresenta um impacto vertical inicial maior.

2.2 INTRODUÇÃO

Apesar de ser considerada uma atividade simples, a corrida envolve uma complexa integração de uma série de movimentos em diferentes articulações e segmentos do corpo, que inclui o ângulo do tronco, balanços dos braços, comprimento do passo, levantamento da perna de trás e por fim o padrão de aterrissagem do pé no solo[1, 2]. Atenção especial vem sendo dada para o padrão de aterrissagem do pé, pois acredita-se que as forças verticais de reação ao solo que são transmitidas para os membros inferiores a cada toque do pé durante corrida seja a principal causa das lesões relacionadas a esse esporte[3-6]. A adoção de determinadas estratégias de aterrissagem pode ser uma das principais formas de se atenuar as forças de impacto vertical que podem acarretar lesões no sistema musculoesquelético.

Existem três padrões de aterrissagem do pé no solo durante a corrida: retropé, quando o contato inicial do pé com o solo é feito com a parte posterior do pé; mediopé, quando a parte posterior e anterior do pé tocam simultaneamente no solo; e antepé, quando a aterrissagem do pé é realizada com a parte anterior do pé. Acredita-se que a maioria dos praticantes de corrida realize a aterrissagem do pé no solo com o retropé[2, 7]. A utilização de calçados esportivos com aumento da espessura e amortecimento na região do calcâneo é referida como um dos motivos que leva a esse predomínio do padrão de retropé durante a corrida[5]. Outro fator que pode influenciar o padrão de aterrissagem do pé é a orientação que é passada aos corredores, e há algum tempo os profissionais que trabalham com corredores recreacionais preconizam que a maneira "correta" de correr seria com padrão de retropé, apesar de não haver evidências que suportem tão raciocínio. O conhecimento sobre as características biomecânicas entre os padrões de aterrissagem para os profissionais da área é importante, já que o padrão de aterrissagem pode estar relacionado com as lesões musculoesqueléticas relacionada à prática desse esporte.

Até o momento os autores não encontraram revisões sistemáticas que abordem os diferentes aspectos relacionados às estratégias de aterrissagem do pé durante a corrida. Em virtude do aumento do interesse da comunidade científica em relação ao tema, e das dúvidas que existem sobre como se comportam corredores com determinado padrão, esta revisão sistemática surge no intuito de contribuir com os pesquisadores e profissionais que trabalham com corredores. Desta forma, o objetivo desta revisão sistemática foi revisar na literatura as características biomecânicas relacionadas aos tipos de padrões de aterrissagem no solo durante a corrida.

2.3 MÉTODOS

2.3.1 Processo de revisão e critérios de elegibilidade

Para a realização desta revisão sistemática foi utilizado as diretrizes propostas pelo PRISMA *(Preferred Reporting Items for Systematic Reviews and Meta-Analyses)*[8]. Foi realizada uma busca nas bases de dados eletrônicas Medline via Pubmed, Embase, Lilacs, Scielo e Sportdiscus até novembro de 2011. Não houve restrição quanto ao período de publicação e idioma dos estudos. Com objetivo de aumentar a sensibilidade e precisão da busca, os descritores utilizados na estratégia de busca foram adaptados para cada base de dados, sendo explorada de acordo com as características das bases. As estratégias de busca completas estão demonstradas na tabela 1. Também foi realizada uma busca nas referências bibliográficas dos artigos encontrados.

Tabela 1. **Estratégias de buscas**

EMBASE	**PUBMED**	**SPORTDISCUS**
1. marathon runner	1. running	1. running
2. running	2. jogging	2. foot
3. treadmill exercise	3. (1 OR 2)	3. (1 AND 2)
4. jogging	4. foot	
5. (1 OR 2 OR 3 OR 4)	5. (3 AND 4)	**LILACS / SCIELO**
6. foot	6. <Limit> humans	1. running
7. (5 AND 6)	7. (5 AND6)	2. foot
8. <Limit> humans		3. (1 AND 2)
9. (5 AND 8 AND 9)		

Foram considerados delineamentos potencialmente elegíveis para a revisão os estudos transversais, casos-controles, prospectivos e retrospectivos, que compararam características biomecânicas entre os tipos de padrões de aterrissagem no solo durante a corrida. Foram incluídos apenas estudos que avaliaram sujeitos com idade maior ou igual a 18 anos, não havendo restrição se os estudos avaliaram participantes com presença ou não de lesões musculoesqueléticas, e ao tempo e tipo de atividade física praticada pelos participantes no estudos. Os artigos que avaliaram participantes durante a marcha, ou que avaliaram sujeitos com apenas um padrão de aterrissagem, não foram incluídos no estudo, já que impossibilitaria qualquer tipo de comparação entre os padrões de aterrissagem.

Dois revisores independentes avaliaram e selecionaram potenciais estudos para inclusão inicialmente através da leitura dos títulos e resumos, aplicando os critérios de inclusão já descritos. Discordâncias foram solucionadas por um terceiro revisor. Os artigos selecionados através da leitura dos títulos e resumos tiveram seus textos completos acessados e avaliados da mesma forma.

2.3.2 Extração e análise dos dados

Após a seleção dos estudos que preencheram os critérios de inclusão, um examinador independente realizou a extração dos dados dos estudos incluídos. As informações que foram extraídas de cada estudo incluem: tipo de desenho do estudo; tamanho da amostra; característica da população do estudo, onde e como foi realizada a avaliação, e variáveis analisadas.

As variáveis encontradas nos estudos foram divididos em três categorias biomecânicas: variáveis espaços-temporais, cinemáticas e cinéticas. Das diversas variáveis encontradas nos estudos incluídos, foram selecionadas apenas as variáveis que foram objetos de pelo menos dois estudos para que fosse possível realizar uma comparação entre os resultados. Desta forma, foram selecionadas as variáveis cinemáticas (posição do pé no contato com o solo; angulação da articulação de membros inferiores); cinéticas (picos de força de reação ao solo, taxa de carregamento vertical e rigidez de membros inferiores) e espaços-temporais (tempo de contato do pé com o solo; largura do passo; cadência e velocidade).

2.3.3 Avaliação do risco de viés

Dois examinadores independentes realizaram a avaliação do risco de viés dos artigos incluídos, e quando não houve consenso um terceiro examinador solucionou as discordâncias. Devido a ausência de uma escala para avaliar o risco de viés quando existem diferentes delineamentos de estudos incluídos em uma revisão sistemática, o mesmo acontecendo para estudo biomecânicos, a avaliação foi realizada através de uma versão modificada da escala criada por Downs & Black[9], com a adição de alguns itens que são relevantes para o contexto da revisão, como informações referente a prática de corrida e a forma em que foram avaliados os participantes (velocidade, tipo de calçado). A escala utilizada foi composta por nove itens, sendo que cada item foi classificado como SIM (+), que representa baixo risco de viés, e NÃO (-), que representa alto risco de viés conforme a tabela 2.

Tabela 2. Descrição do método de avaliação do risco de viés.

Critério	Descrição dos critérios de avaliação	Resposta
População do estudo	Sem o conhecimento das características demográficas e de rotina de corrida é impossível realizar uma extrapolação dos resultados. Os estudos que descreveram as características demográficas e gerais do treinamento de corrida, permitindo identificar o tipo de corredor que foi avaliado, receberam a resposta SIM (+). Os que não descreveram receberam a resposta NÃO (-).	**SIM:** baixo risco de viés **NÃO:** alto risco de viés
Amostra do estudo	O cálculo amostral é imprescindível para saber quantos sujeitos são necessários para responder determinada pergunta. Os estudos que relataram o cálculo amostral receberam a resposta SIM. Os que não relataram o cálculo amostral receberam a resposta NÃO.	**SIM:** baixo risco de viés **NÃO:** alto risco de viés
Seleção dos sujeitos	Para diminuir o risco viés de seleção, a inclusão no estudo deve ser realizada de forma aleatória. Os estudos que realizaram a seleção dos sujeitos de forma aleatória, ou que tenham avaliado todos os corredores da população alvo receberam a resposta SIM. Os que não selecionaram os sujeitos de forma aleatória receberam a resposta NÃO.	**SIM:** baixo risco de viés **NÃO:** alto risco de viés
Descrição das variáveis	Para diminuir o risco viés de seleção das variáveis, todas as variáveis analisadas deveriam estar relatados nos métodos. Os estudos em que as variáveis foram descritas nos métodos, e não na seção de resultados receberam a resposta SIM. Os que não descreveram as variáveis nos métodos receberam a resposta NÃO.	**SIM:** baixo risco de viés **NÃO:** alto risco de viés
Apresentação dos resultados	Os dados com distribuição normal devem ser relatados em média e desvio padrão, e os com distribuição não-normal em mediana e intervalo interquartil. Os estudos que apresentaram os resultados através de medidas de tendência central e dispersão receberam a resposta SIM. Os que não apresentaram o resultado desta forma receberam a resposta NÃO.	**SIM:** baixo risco de viés **NÃO:** alto risco de viés
Velocidade da corrida	A padronização da velocidade da corrida é importante para diminuir o viés na análise dos resultados entre os sujeitos, já que as características biomecânicas variam com a velocidade. Os estudos que padronizaram a velocidade dos corredores durante a aquisição dos dados receberam SIM. Os que não realizaram padronização da velocidade receberam a resposta NÃO.	**SIM:** baixo risco de viés **NÃO:** alto risco de viés
Avaliação em duas situações	A utilização de calçados pode influenciar no padrão de aterrissagem durante a corrida. Os estudos que realizaram a avaliação nas duas situações (calçado e descalço) receberam SIM. Os que não avaliaram a avaliação nas duas situações receberam a resposta NÃO.	**SIM:** baixo risco de viés **NÃO:** alto risco de viés
Descrição dos calçados	É necessária a descrição das propriedades dos calçados, já que isto pode influenciar no padrão de aterrissagem. Os estudos que descreveram as propriedades dos calçados receberam SIM. Os que não descreveram receberam a resposta NÃO.	**SIM:** baixo risco de viés **NÃO:** alto risco de viés
Histórico de lesões	Acredita-se que o histórico de lesões musculoesqueléticas e presença de dor durante a corrida pode influenciar o padrão de aterrissagem. Os estudos que relataram o histórico de lesões relacionadas à corrida assim como a presença de dor no momento da avaliação receberam SIM. Os estudos que não relataram essas informações receberam NÃO.	**SIM:** baixo risco de viés **NÃO:** alto risco de viés

2.4 RESULTADOS

A busca realizada nas bases de dados identificou um total de 1648 artigos, sendo que 134 eram duplicatas. Após aplicação dos critérios de inclusão e seleção através das etapas descritas nos métodos, 12 artigos foram elegíveis para a revisão. O fluxograma do processo completo de seleção e inclusão dos artigos está demonstrado na figura 1.

2.4.1 Avaliação do risco de viés

A avaliação do risco de viés dos estudos incluídos demonstrou uma pontuação baixa, o que representa um alto risco de viés, conforme demonstrado na Tabela 3. Os itens em que houve maior risco de viés nos estudos foram referentes à amostra do estudo, no qual os artigos não apresentaram cálculo amostral; a forma de avaliação, em que os corredores precisavam ter sido avaliados descalços e com calçados, e em relação à descrição das propriedades do calçado.

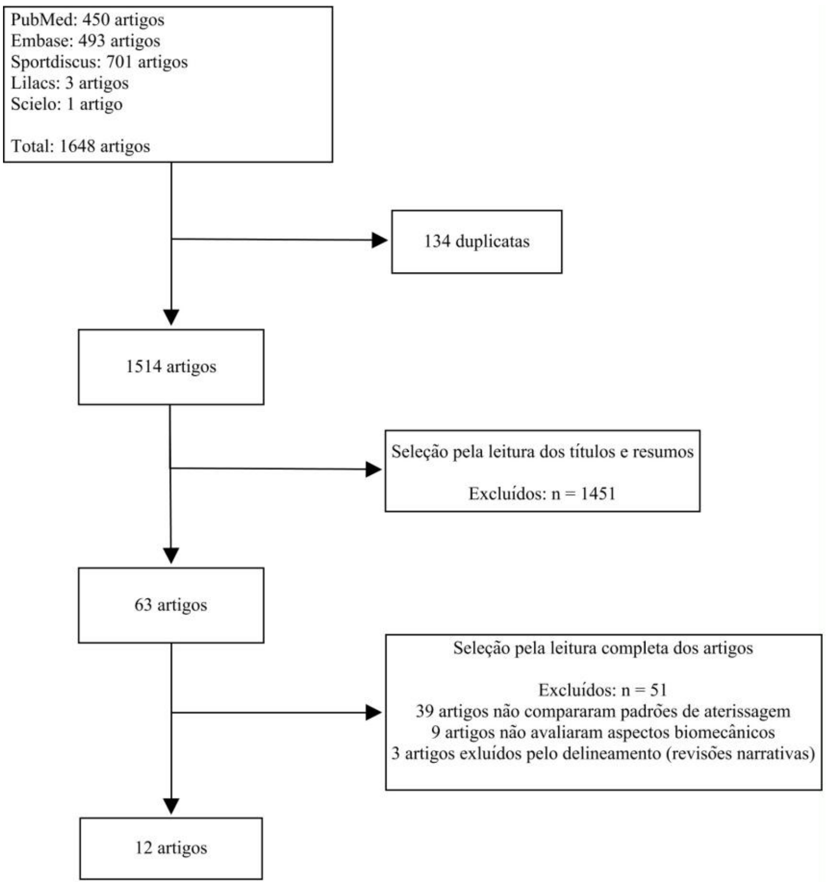

Figura 1. Fluxograma do processo de seleção e inclusão dos artigos na revisão sistemática

Tabela 3. Pontuação dos critérios de avaliação de qualidade dos artigos

Artigos	1	2	3	4	5	6	7	8	9	Pontuação
Cavanagh 1980[6]	+	-	-	+	+	+	-	-	-	**4**
Oakley 1988[10]	+	-	+	-	+	+	+	+	+	**7**
Nilsson 1989[11]	-	-	-	+	+	+	-	-	-	**3**
Ardigo 1995[12]	-	-	-	+	+	+	-	-	-	**3**
Hamil 2000[13]	-	-	-	+	+	+	-	-	+	**4**
Williams 2000[14]	-	-	-	+	+	+	-	-	-	**3**
Laugthon 2003[15]	-	-	-	+	+	-	-	-	-	**2**
Arendse 2004[16]	+	-	-	+	+	-	-	-	-	**3**
Stackhouse 2004[17]	-	-	-	+	-	+	-	-	-	**2**
Hasegawa 2007[2]	-	-	+	+	+	-	-	-	-	**3**
Pohl 2008[18]	+	-	-	+	+	-	-	-	+	**4**
Lieberman 2010[5]	+	-	-	+	+	-	-	-	-	**3**

(1) população do estudo; (2) amostra do estudo; (3) seleção dos sujeitos; (4) descrição das variáveis; (5) apresentação dos resultados; (6) velocidade da coleta; (7) avaliação em duas situações; (8) descrição dos calçados; (9) histórico de lesões.
Pontuação = pontuação dos itens "+" (SIM).

2.4.2 Descrição dos estudos

A descrição das características dos estudos está demonstrada na Tabela 4. Todos os estudos apresentaram um delineamento transversal, gerando uma amostral total de 453 corredores avaliados. Apenas um estudo avaliou corredores profissionais[2], enquanto todos os outros foram compostos por corredores ativos com idade variando de 18 a 45 anos. A maioria dos estudos foi realizado em laboratório, e apenas um estudo avaliou os corredores em uma esteira[12]. Os corredores foram avaliados utilizando calçados em 9 estudos, sendo que apenas um estudo[10] avaliou os corredores em duas situações (calçados e descalços).

Dos doze artigos incluídos, seis[5, 10, 11, 13, 14, 17] compararam o padrão de retropé com padrão de antepé, quatro estudos[6, 10, 11, 16] compararam padrão de retropé com padrão de mediopé e um estudo[2] realizou comparação entre os três padrões de aterrissagem. Outro estudo[18] comparou o padrão de retropé com antepé e outro padrão que eles nomearam de "toe-running", no qual a parte posterior do pé não toca no solo durante a corrida. Em relação às variáveis encontradas, oito estudos investigaram variáveis cinéticas, seis estudos investigaram variáveis cinemáticas e apenas quatro artigos investigaram as variáveis espaços-temporais. Cinco estudos avaliaram mais de um tipo de categoria biomecânica. Foi encontrado um total de 79 variáveis diferentes nos estudos selecionados, sendo que apenas 20 variáveis foram incluídas por se repetirem em mais de um estudo.

2.4.3 Variáveis espaços-temporais

As variáveis avaliadas pelos quatros estudos[2, 6, 12, 16] foram: cadência, comprimento do passo, velocidade e tempo de contato do pé com o solo. Arendse et al[16] não encontraram diferenças no comprimento do passo entre o padrão de retropé e mediopé. Já no estudo de Ardigo et al[12] aqueles que correram com padrão de antepé apresentaram um passo menor que o padrão de retropé. Nesse mesmo estudo os corredores com padrão de retropé apresentaram uma menor cadência durante a corrida. Apenas um estudo[16] comparou diretamente velocidade entre corredores com padrão de mediopé e retropé, não encontrando diferença significativa entre eles. Dois estudos[2, 6] avaliaram o tempo de contato do pé com o solo, e os corredores com padrão de retropé apresentaram um maior tempo de contato.

2.4.4 Variáveis cinemáticas

A descrição dos resultados das variáveis cinemáticas analisados pelos estudos está detalhada na Tabela 5. As diferenças significativas dos corredores com padrão de retropé em relação ao padrão de antepé foram: maior pico de eversão do retropé; menor excursão total de eversão do retropé; menor excursão total de dorsiflexão do tornozelo; contato inicial do pé em dorsiflexão e menor inversão do retropé; maior excursão total de flexão do joelho, além de uma menor velocidade de eversão do retropé e dorsiflexão do tornozelo. Todos os estudos, exceto o estudo de Hasegawa et al[2] que utilizou apenas uma câmera simples para captura das imagens, realizaram a investigação das variáveis cinemáticas através de um sistema tridimensional, com uso de múltiplas câmeras.

2.4.5 Variáveis cinéticas

A descrição dos resultados das variáveis cinéticas analisados pelos estudos está detalhada na Tabela 6. Corredores com padrão de retropé apresentaram valores significantemente maiores em relação ao 1º pico de força de reação vertical ao solo (FRV1) quando comparados com padrão de mediopé e antepé, sendo que em dois estudos[6, 11] este 1º pico de força vertical esteve ausente em corredores com esses padrões. Já em relação ao pico de força de reação ântero-posterior ao solo (FRAP), corredores com padrão de mediopé ou antepé apresentaram valores significantemente maiores em relação ao padrão de retropé. Quanto ao 2º pico de força de reação vertical ao solo (FRV2) e taxa de carregamento vertical, os estudos apresentaram resultados contraditórios. Todos os estudos que analisaram as variáveis cinéticas utilizaram plataforma de força com frequência de aquisição de dados variando de 480 a 4800 Hz, enquanto que dois estudos utilizaram acelerômetros.

Tabela 4. Descrição das características dos estudos.

Estudo	Delinemanento do estudo	Tamanho da amostra	Participantes (corredores)	Padrão de aterrissagem	Local da avaliação	Condição de avaliação	Variáveis
Cavanagh 1980[6]	Transversal	17	Ativos com idade média de 24 anos	RFS x MFS	Laboratório	Calçado	Cinética Espaço-temporal
Oakley 1988[10]	Transversal	18	Ativos com idade média de 22 anos	RFS x MFS	Laboratório	Descalço / Calçado	Cinética
Nilsson, 1989[11]	Transversal	12	Ativos com idade média de 26 anos	RFS x MFS	Laboratório	Calçado	Cinética
Ardigo 1995[12]	Transversal	8	Ativos com idade média de 24 anos	RFS x FFS	Esteira	-	Espaço-temporal
Hamill 2000[13]	Transversal	5	Ativos sem lesão no momento da avaliação	RFS x FFS	Laboratório	Calçado	Cinética
Willians 2000[14]	Transversal	18	Ativos com idade entre 18 e 45 anos	RFS x FFS	Laboratório	Calçado	Cinética Cinemática
Laughton 2003[15]	Transversal	15	Ativos com idade média de 22 anos	RFS x FFS	Laboratório	Calçado	Cinética Cinemática
Arendse 2004[16]	Transversal	20	Ativos com idade média de 33 anos	RFS x MFS	Pista	-	Cinética Cinemática Espaço-temporal
Stackhouse 2004[17]	Transversal	15	Ativos com idade entre 18 e 45 anos e sem lesão no momento da avaliação	RFS x FFS	Laboratório	Calçado	Cinemática
Hasegawa 2007[2]	Transversal	283	Maratonistas de elite	RFS x MFS x FFS	Rua	Calçado	Cinemática Espaço-temporal
Pohl 2008[18]	Transversal	12	Ativos com idade média de 21 anos sem lesão nos últimos 6 meses	RFS x FFS	Laboratório	Descalço	Cinemática
Lieberman 2010[5]	Transversal	30	Ativos com idade entre 19 e 38 anos e sem lesão nos últimos 6 meses	RFS x FFS	Laboratório / Pista	Descalço / Calçado	Cinética

Tabela 5. Descrição dos resultados das variáveis cinemáticas.

Estudo	Padrão	Pico de eversão do retropé (°)	Eversão total do retropé (°)	Dorsiflexão total do tornozelo (º)	Ângulo do tornozelo no CI (°)	Flexão total do Joelho (º)	Ângulo do joelho no CI (º)	Inversão do retropé no CI (°)	Velocidade de eversão do retropé (°/s)	Velocidade de dorsiflexão (°/s)
Willians 2000[14]	Retropé		11,5 (1,6)	22,0 (2,9)	+7,6 (5,3)	28,9 (2,3)	14,0 (5,7)	2,5° (2,8)	243,2 (56,6)	316,2 (32,9)
	Antepé		17,5 (5,7)	29,9 (7,1)	-6,2 (7,2)	25,2 (7,6)	20,1 (8,6)	8,5° (4,1)	361,4 (82,8)	420,5 (93,3)
Laughton 2003[15]	Retropé		13,7 (4,0)	19,2 (4,8)		34,7 (3,0)				
	Antepé		16,4 (3,9)	31,6 (4,3)		30,5 (3,8)				
Arendse 2004[16]	Retropé				+13,2 (4,5)		27,3 (5,3)			
	Mediopé				-11,5 (5,8)		27,2 (6,4)			
Stackhouse 2004[17]	Retropé	10,5*	13,6*			34,7 (4,2)			190,9*	317,4 (48,5)
	Antepé	8,8*	16,4*			30,5 (4,2)			270,6*	426,7 (78,1)
†Hasegawa 2007[2]	Retropé							32%		
	Mediopé							62,5%		
	Antepé							50%		
Pohl 2008[18]	Retropé	11,1 (2,8)	12,0 (2,7)							
	Antepé	9,1 (3,0)	17,9 (4,3)							

Os dados estão expressos em média e desvio-padrão, exceto †Hasegawa 2007, em que foi avaliado apenas se os corredores estavam em posição de inversão.

*o autor não relata o desvio-padrão.

CI: contato inicial do pé no solo.

Ângulo do tornozelo no contato inicial: valores negativo representam flexão plantar.

Tabela 6. Descrição dos resultados das variáveis cinéticas.

Estudo	Padrão de aterrissagem	1º pico de força de reação vertical ao solo (PC)	2º pico de força de reação vertical ao solo (PC)	Taxa de carregamento vertical (PC/s)	Pico de força de reação ântero-posterior ao solo (PC)	Rigidez da perna (kN/m)	Rigidez do tornozelo (N.m/°)	Rigidez do joelho (N.m/°)
Cavanagh 1980[6]	Retropé	2,2 (0,4)	2,8 (0,3)		0,4 (0,05)			
	Mediopé	ausente	2,7 (0,2)		0,4 (0,1)			
#Oakley 1988[10]	Retropé	1,5 x maior	2,6 (0,2)					
	Antepé	-	2,7 (0,2)					
*Nilsson 1989[11]	Retropé	2,6	3,0					
	Antepé	ausente	2,9					
Hamill 2000[13]	Retropé					16,0 (2,5)	18,8 (2,9)	17,9 (5,4)
	Antepé					23,1 (5,5)	14,4 (4,0)	22,5 (4,7)
Williams 2000[14]	Retropé		2,6 (0,2)	64,2 (21,1)	0,3 (0,1)			
	Antepé		2,8 (0,2)	35,6 (13,4)	0,4 (0,1)			
Laughton 2003[15]	Retropé		2,5 (0,1)	58,6 (9,8)	0,4 (0,05)	6,9 (1,0)	14,2 (3,5)	4,8 (1,0)
	Antepé		2,6 (0,3)	52,9 (15,0)	0,5 (0,1)	8,5 (1,4)	7,1 (2,0)	5,5 (1,3)
Arendse 2004[16]	Retropé	1,2 (0,2)	1,2 (0,3)	49,9 (9,3)				
	Mediopé	0,9 (0,3)	0,9 (0,3)	37,3 (7,4)				
Lieberman 2010[5]	Retropé	1,9 (0,7)		69,7 (28,7)				
	Antepé	0,6 (0,2)		64,6 (70,1)				

#o autor apenas descreve a razão do evento em um padrão em relação ao outro.

*o autor não relata o desvio-padrão

2.5 DISCUSSÃO

Esta revisão sistemática identificou um total de 12 artigos que compararam aspectos biomecânicos referentes aos padrões de aterrissagem do pé no solo durante a corrida. O resultado apontou que o padrão de retropé apresentou diferenças em relação às variáveis espaço-temporais, cinemáticas e cinéticas entre o padrão de retropé quando comparados com o padrão de mediopé ou antepé.

A análise do risco de viés dos estudos demonstrou que a maioria dos estudos apresentou uma pontuação baixa. Apenas um estudo[10] apresentou uma pontuação alta, sendo o único estudo a citar as propriedades do calçado utilizado e ter realizado a avaliação dos corredores calçados e também descalços. Os outros estudos avaliaram os corredores em apenas uma situação (calçado ou descalço), ou corredores de determinado padrão com a utilização de calçado (geralmente o padrão de retropé), e corredores com padrão mediopé ou antepé avaliados descalços, o que representa um alto de risco de viés na interpretação da comparação entre os padrões. Pode-se observar também que poucos estudos relataram a utilização de um cálculo amostral.

A avaliação da maioria dos estudos incluídos foi realizada em um ambiente laboratorial, que representa um ambiente mais controlado e consequentemente mais confiável em relação ao controle das variáveis estudadas. Porém, pode se questionar se neste tipo de avaliação ocorrem mudanças no padrão de corrida dos participantes, já que não é o ambiente que eles costumam praticar a corrida. Um único estudo[12] avaliou os corredores em uma esteira (cadência e largura do passo), o que dificulta qualquer comparação destes resultados com estudos em que os indivíduos não correram em esteiras. Mok et al[19] encontraram que a avaliação da corrida realizada na esteira gera alterações como menor largura do passo e tempo de apoio no solo, além de uma menor amplitude de movimento do tornozelo e flexão do joelho no contato inicial, o que pode afetar o padrão de aterrissagem do pé.

Os resultados demonstraram que existem diferenças cinemáticas entre os padrões de aterrissagem durante a corrida, que ocorrem principalmente no complexo tornozelo-pé no momento do contato inicial com o solo. O padrão de antepé e mediopé é caracterizado por um contato inicial do pé em flexão plantar, o que leva a uma maior flexão do joelho nesta fase, minimizando assim o deslocamento vertical do centro de massa, o que pode significar uma economia de energia durante a corrida[14, 16]. Pelo fato de apresentar maior flexão de joelho no contato inicial, os corredores com padrão de antepé apresentam uma menor amplitude de flexão do joelho[14, 15, 17] quando comparado com os corredores com padrão de retropé, que pelo fato de tocar o solo com o joelho quase em extensão é necessário realizar uma maior flexão do joelho no restante do ciclo da corrida.

Os corredores com padrão antepé tocam o solo em um ângulo de inversão maior comparado com o padrão retropé[14], e ambos os padrões entram em eversão imediatamente após o contato inicial, porém com velocidade maior no padrão de antepé [14, 17]. Por realizar o contato inicial com maior inversão, quem corre com padrão antepé realiza uma amplitude maior de eversão[14, 15, 17, 18], porém ao comparar o pico de eversão, pode-se observar que os valores são significantemente maiores no padrão retropé[17, 18]. Essas diferenças cinemáticas provavelmente devem acarretar exigências musculares diferentes dos inversores e eversores do pé entre os padrões de aterrissagem.

Em relação às variáveis cinéticas, a principal diferença entre os padrões são os maiores valores por parte do padrão retropé para a FRV1[5, 10, 16], sendo que em dois estudos[6, 11] este primeiro pico de força, também conhecido como impacto transiente, esteve ausente em corredores com padrão antepé e mediopé. O impacto transiente é caracterizado por forças abruptas de alta magnitude que são transferidas para os membros inferiores quando o contato com o solo é realizado com o calcanhar, no qual pouca energia é dissipada devido à posição em dorsiflexão do tornozelo[5]. Corredores com padrão de antepé e mediopé por tocarem o solo com o tornozelo em flexão plantar conseguem converter as forças verticais em energia cinética rotacional através do controle do tríceps sural e tendão de Aquiles, e consequentemente diminuir o impacto nos membros inferiores[5]. Uma menor rigidez do tornozelo no padrão de antepé[13, 15] também auxilia neste processo.

Ao analisar os resultados referentes à taxa de carregamento vertical, pode-se notar que o padrão de antepé e mediopé gera valores menores quando comparados com o retropé, apesar de que em dois estudos diferenças significativas para a taxa de carregamento não foram observadas entre os padrões[5, 15]. A taxa de carregamento vertical avalia o quanto rápido as forças de impactos são geradas quando ocorre o contato inicial do pé com o solo e pode estar relacionada com lesões musculoesqueléticas, especialmente com as fraturas por estresse[20]. Essa menor taxa de carregamento vertical encontradas nos padrões de antepé e mediopé ocorre devido a ação do tríceps sural e tendão de Aquiles, que conseguem que o impacto seja transferido por um período de tempo maior e não de forma rápida e brusca.

Uma das limitações desta revisão é a possibilidade de não termos encontrado algum estudo na busca, mesmo utilizando uma estratégia de busca abrangente e termos pesquisado nas principais bases de dados da área. Outra limitação se deve pelo fato da revisão ter sido realizada com estudos biomecânicos, que geralmente aporta um grande número de variáveis, que são avaliadas de formas diferentes, o que dificulta realizar comparações entre os estudos pela falta de padronização metodológica entre eles.

O conhecimento sobre as características biomecânicas entre os padrões de aterrissagem para os profissionais da área (treinadores, fisioterapeutas e médicos) é importante no momento de orientar os corredores sobre que padrão adotar durante a corrida, já que o padrão de aterrissagem pode estar associado com as lesões musculoesqueléticas relacionadas à prática desse esporte.

2.6 CONCLUSÃO

A presente revisão sistemática demonstra que existem diferenças entre os padrões de aterrissagem, principalmente entre o padrão retropé e os padrões mediopé e antepé, para as variáveis espaços-temporais, cinemáticas e cinéticas. Corredores com padrão retropé estão expostos a um maior impacto no momento do contato inicial do pé no solo durante a corrida, enquanto que os corredores que tocam o solo com antepé e mediopé por tocarem o solo em plantiflexão absorvem esse impacto através da ação dos tríceps sural e tendão calcâneo.

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-CAPÍTULO 3-

DETERMINATION OF THE FOOT STRIKE PATTERN IN RUNNERS BELONGING TO A RUNNING TEAM

(SUBMETIDO PARA A "THE INTERNATIONAL SPORTMED JOURNAL")

DETERMINATION OF THE FOOT STRIKE PATTERN IN RUNNERS BELONGING TO A RUNNING TEAM

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Running title: **Foot strike pattern in runners**

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3.1 Abstract

Background: The number of runners has been increasing as well as the number of injuries related to this sport. The knowledge of the foot strike patterns of the runners has become necessary since there is a possible relationship between the landing pattern of the foot against the ground during running and the increased incidence of musculoskeletal injuries in runners.

Research question: The objective of this study was to determine the distribution of the foot strike patterns in recreational runners during typical training running pace.

Type of study: Cross-sectional study

Methods: The present study was conducted with recreational runners who practice with running coach. A high-speed camera (image acquisition frequency of 250 Hz) was used to analyze the landing pattern and photocells were used to register the runners´ speed. The foot strike patterns were classified into three categories: rearfoot, midfoot and forefoot. The description of the foot strike pattern and the characteristics of the participants were done through descriptive statistics. The inter and intra observer reliability was determined with the percentage of concordance.

Results: Fifty three runners were evaluated with an average speed of 12.6 km/h. Ninety-eight point one (98.1%) percent of the runners touched the ground with their rearfoot first. Only one runner touched the ground with the midfoot first and none touched it with the forefoot. The evaluation method for determining foot strike patterns had a 96.2% and 100% inter observer and intra observer reliability respectively.

Conclusion: The results of the study showed that the adult recreational runners from this study who practice with running coach have almost exclusively the rearfoot pattern during running.

Keywords: Foot Strike, Landing, Running, Injuries, Prevention

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3.2 INTRODUCTION

Running is one of the most practiced sports around the world, but the number of injuries related to this sport is high, with injury rates ranging between 19-79%[1]. Many studies have investigated risk factors for running-related injuries, but there is limited evidence that the majority of factors, such as type of training surface, anatomic factors, and type of foot, can be regarded as risk factors for running injuries[1-6]. The literature demonstrates that only weekly running distance and previous injuries can be stated with significant evidence, as risk factor for running injuries[1]. Even the relationship between vertical forces and injury has never been shown conclusively. While some studies demonstrated correlation between high rates of vertical forces and running injuries[7, 8], others have failed to find this correlation[9, 10].

Given the absence of evidence on risk factors that explain the great number of injuries in runners, special attention has been given to the part of the foot that strikes the ground first, since the foot is the segment of the body receives all the forces of the ground directly[11-13]. It is believed that the main cause of the injuries related to running is the overload that occurs with each time the foot strikes the ground, leading to a marked increase of the vertical forces that are transmitted to the lower limbs[14]. This is how the adoption of certain strategies for the landing of the foot on the ground during running might be responsible for a greater protection of the musculoskeletal system against injuries[12].

Despite the importance of the foot strike pattern during running, only three studies[11,13,15] have evaluated the distribution of the foot strike patterns among runners. All studies were realized during race, with foot strike evaluation done by only one stride. They evaluated only half-elite marathoners and race participants, not allowing any inference for recreational runners who do not to practice for or participate in specific races. Therefore, the main objective of this study was to determine foot strike pattern distribution among recreational runners during typical training running pace.

3.3 METHODS

A descriptive cross-sectional study was done in order to identify the foot strike pattern distribution of recreational runners who practice with running coach. Individuals were invited to participate of the study in places where there are high numbers of people practicing running. They needed to be older than 18 years of age, had to wear shoes during the evaluation and had to have practiced running for at least 6 months. There were no restrictions regarding weekly running distance. All participants signed an informed consent, and the study was approved by the ethics committee of the University City of São Paulo. Participants fulfilled a form with information about demographic characteristics (age, weight, height and gender), practice time, presence of pain at the time of the evaluation and history of injuries during the last 6 months. It was decided to collect information about pain in the moment of evaluation or recent previous injury due a possible influence on foot strike patterns of runners.

After answering the questions, the participants were forwarded to the place where the image acquisition was performed. It was a 50-meter long track and a camera (Casio EX FX1) was located halfway the path for taking high-speed images (image acquisition frequency of 250 Hz and 250.s^1 of shutter speed). The camera was positioned on a 15 cm high tripod, 2 meters away from the running line. The participants were instructed to run at a speed that they found comfortable. A pair of emitting photocells (TC-Timing System) was positioned next to the camera 2 meters away from it on each side and the receptor photocells were placed 4 meters away from each of the emitting ones, in front of each of them (Figure 1). The participants ran twice to and from across the path for a total of 200 meters. This way each participant ran in front of the camera four times and four landings were recorded for each foot.

3.3.1 Image analysis

The videos with the images of foot strike patterns were captured and later analyzed. The four times that the participants crossed the camera were recorded and evaluated and the analysis was done according to the lateral view of the foot. When there were different types of foot strike patterns in one participant, the most frequent pattern was chosen. Foot strike pattern was defined by the part of the foot that collides with the ground first and fell into three classifications[8]: rearfoot (figure 2a), when the runner lands with the heel; (2) midfoot (figure 2b), when the runner lands with the heel and ball of the foot simultaneously; and (3) forefoot (figure 2c), when the ball of the foot lands before the heel comes down. Two independent evaluators performed the analysis of all images, and when there were any differences in their interpretations a third observer would solve the differences.

3.3.2 Statistical analysis

A descriptive statistical analysis with a simple frequency distribution and percentage calculation for categorical data and with measures of central tendency and dispersion for continuous data was performed to describe the foot strike pattern of runners, and to identify the participants' characteristics. Evaluation of normality was done for continuous data (age, weight, height, body mass index, time of practice and average speed during evaluation) through analysis of the symmetry of the curve. Data with normal distribution were presented in mean value and standard deviation while data with non-normal distribution were given with median value and interquartile range. Inter and intra observer reliability was determined according to the percentage of concordance. Analyses were performed through SPSS 17.0 software.

3.4 RESULTS

The foot strike pattern was analyzed in 53 runners (Table 1). The runners had a mean age of 42 years (SD = 11), with a median running practice of five years (IQ = 7). Nearly 20% of runners had a history of a musculoskeletal injury in the previous six months and 19% had pain at the moment of the running evaluation. The foot and ankle were the anatomic areas most commonly implicated in runners who had pain at the moment of the evaluation. The knee was the anatomic area most commonly implicated in musculoskeletal injuries in the previous six months.

Regarding the distribution of foot strike patterns (Table 2), 52 runners (98.1%) touched the ground with the heel (rearfoot pattern) first. Only one runner touched the ground with the ball of the foot and heel simultaneously (midfoot pattern) and no runner touched the ground with the ball of the foot first. The mean speed during the acquisition of images was 12.6 km/h (SD = 2.3). The evaluation method for identifying foot strike pattern had a 96.2% and 100% inter and intra observer reliability respectively.

3.5 DISCUSSION

The results showed that the majority of recreational runners who participated in this study were rearfoot strikers. Only one runner had a midfoot strike pattern and none had a forefoot pattern. The mean speed of the runners was approximately 12 km/h and near 20% of the runners referred pain at the moment of the evaluation.

The results of this study differs from those found by Larson et al[15], Kerr et al[13] and Hasegawa et al[11], who found that 88%, 80% and 75% of their participants were rearfoot strikers, respectively. This difference can be explained by the characteristics of the sample that was comprised of recreational runners who ran at a lower average speed (12.6 km/h) than did the half elite marathoners studied by Hasegawa et al[11] (17.7 to 19.6 km/h), and runners from Kerr et al[13] (12.4 a 19.9 km/h). When it was compared with the results from Larson et al, in which participants ran with a pace around 11 km/h, it was noted that the difference about rearfoot strikers' rate was smaller. This supports the theory that the foot strike pattern may be speed dependent.

The results of the present study are interesting because most of the participants were rearfoot strikers. It is worthy of notice that all participants in this study practice with running coach. We think that the foot strike pattern may be not only influenced by the runner´s speed but also by the information the runner could have received. Professionals that work with runners (trainers, physiotherapists and doctors) have been advocating that the "correct" way of running would be making the first contact with the ground with the heel, asking the runners to produce the movement popularly known as "heel-toe running", even studies has demonstrated that the impact forces are higher in this pattern than in midfoot and forefoot strikers during running[12, 16-18].

The type of sole used by the runners would may also influence the foot strike pattern during running[12]. Over time, shoe companies have been increasing the thickness and cushion in the heel region leading to a better feeling of comfort, furthering the adoption of the rearfoot pattern. The efficacy of the use of these special running shoes on running injuries prevention have been questioned since these running shoes was invented. Marti et al[19] in 1984 stated that no special shoe for running had a prophylactic effect on musculoskeletal injuries on runners. It is curious though that for more than 30 years we have been using an artifact for running (running tennis shoes) with the idea we are protecting ourselves from injuries even though there is no scientific evidence that proves the efficacy of this footwear in the prevention of injuries[20-22].

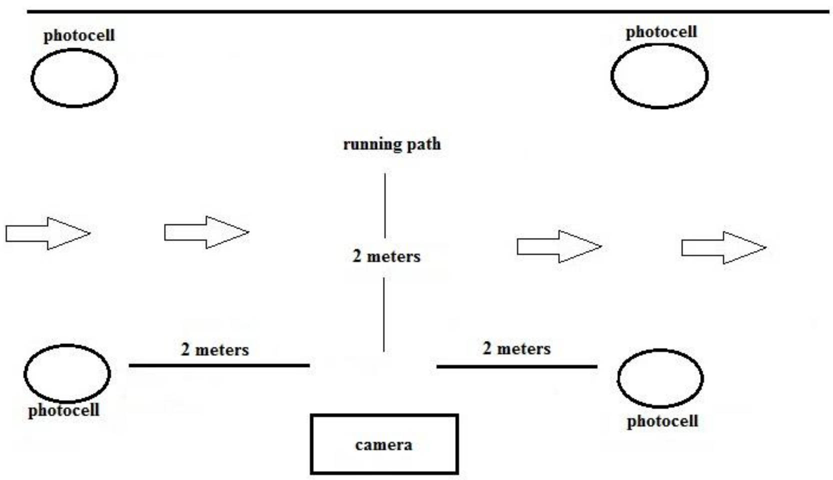
A limitation of the present study is due to the fact that all participants practice with running coach and the trainers guide the runners into executing a rearfoot strike pattern. The method of image acquisition was the same one used in other studies published in the area[11, 13, 15], but we used a camera image acquisition frequency of 250 Hz. This frequency is more adequate than ones used in the previous two studies that used cameras with a frequency of 120Hz and 60hz[11, 13], since the precision in the evaluation of foot strike pattern during running is directly related to the increased frequency of image acquisition[23]. This study brings important information on the issue of foot strike pattern, because none of studies in the literature had found a proportion of rearfoot pattern as high as found in our study. Future studies are needed to establish the factors that really determine the foot strike pattern and if there are a association between foot strike and running related injuries.

3.6 CONCLUSION

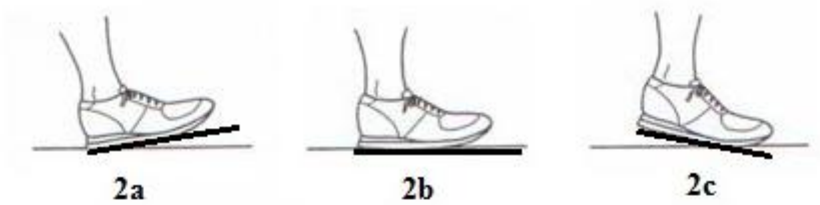
The results of this study showed that the participants from this study, who were adult recreational runners that practice with running coach and with a pace around 12km/h, have almost exclusively a rearfoot strike pattern during running. Only one runner showed a midfoot patterns and no runner had a forefoot pattern.

3.7 APPENDIX

1- Figure 1. Schematic representation of the area for the image acquisition during running.



2- Figure 2. Foot strike patterns during running.



3- Table 1. Characteristics of the runners included in this study.

Table 1. Characteristics of the runners included in the study		
Age (years)		42 (10.9)
Weight (Kg)		68.6 (11.8)
Height (cm)		171 (0.09)
BMI (Kg/cm²)		23.1 (0.3)
Self-selected speed (Km/h)		12.6 (2.3)
Practice time (years)*		5 (7)
Gender		
	Men	62.3% (33)
	Women	37.7% (20)
Pain at the moment of evaluation		
	Yes	18.9% (10)
	No	81.1% (43)
Musculoskeletal injury in the previous 6 months		
	Yes	20.8% (11)
	No	79.2% (42)

The continuous data with normal distribution are shown with a mean value and standard deviation
*The continuous data with abnormal distribution are shown with median value and interquartile range.
Categorical data are shown in percentage and number of runners.

4- Table 2. Distribution of foot strike patterns of runners

Table 2. Distribution of foot strike patterns of runners.

Foot strike pattern	n	%
Rearfoot	52	98.1
Midfoot	1	1.9
Forefoot	0	0

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-CAPÍTULO 4-

FOOT STRIKE PATTERNS OF RECREATIONAL RUNNERS DURING TYPICAL TRAINING PACE: A CROSS-SECTIONAL STUDY

(EM PREPARAÇÃO PARA SUBMISSÃO PARA A “THE BRITISH JOURNAL OF SPORTS MEDICINE”)

FOOT STRIKE PATTERNS OF RECREATIONAL RUNNERS DURING TYPICAL TRAINING PACE: A CROSS-SECTIONAL STUDY

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Keywords: Foot Strike, Running, Biomechanics

Word Count: 2479

4.1 ABSTRACT

Background: Special attention has been given to foot strike patterns, since there is a possible relationship between running injuries and the area of the foot that strikes the ground first. Although, the distribution of foot strike patterns wasdefined in the literature only during race conditions and runners usually during races run with a higher pace than during practice's routine. **Objective:** To determine the foot strike patterns of recreational runners during typical training pace. **Methods:** This is a cross-sectional study with runners who were at least 18 years old and were free of injury at the time of evaluation. The analysis was done with a high-speed camera, and photocells were utilized to register the runners' speeds. The foot strikes were classified into three patterns: rearfoot, midfoot and forefoot. Descriptive statistics were used to describe foot strike patterns. The intra-class and inter-class confiability was evaluated with the Kappa coefficient and percentage of concordance. **Results:** 514 runners were evaluated, and they finished the path with an average speed of 12.2 km/h (DP=2.4). 95.1% of the runners were rearfoot strikers, 4.1% were midfoot strikers, and only four runners (0.8%) were forefoot strikers. There were no significant differences between groups (rearfoot strikers versus midfoot or forefoot strikers) for any variable. **Conclusion:** The result of this study demonstrated that great majority of recreational runners was rearfoot strikers.

4.2 INTRODUCTION

Running is one of the most popular types of physical activity in the world, and the numbers of injuries related to this sport is high, with injuries rates ranging between 19% and 79%.[1] Many studies have investigated risk factors for running-related injuries, but there is limited evidence that the majority of factors, such as type of training surface, anatomic factors, and type of foot, can be regarded as risk factors for running injuries.[1-6]

In the absence of evidence that could explain the high numbers of running-related injuries, special attention has been given to the area of the foot that strikes the ground first, since the foot receives directly the forces from the ground.[7-9] It is believed that the main reason for running-related injuries is the overload that occurs when the foot collides with the ground, and this overload supposedly increases by the vertical forces transmitted to the lower limbs.[10] However, until now, studies do not have demonstrated the relationship between the magnitude of ground reaction forces and running injuries. One of the hypotheses that have been discussed is that foot strike strategies could provide higher protection of musculoskeletal structures against injuries[8].

Despite the apparent importance of foot strike during running, only three studies[7, 9, 11] have evaluated the distribution of the foot strike patterns among runners. The three studies[7, 9, 11] were realized during races, and they evaluated foot strike by analyzing only one stride. Moreover, these studies evaluated only elite marathoners and race participants, who usually during races run with a higher pace than during practice's routine. Another interesting factor that should be noted when analyze the results from the studies done during races,[7, 9, 11] is that speed was not controlled at the time of foot strike pattern identification, as well as personal characteristics and training information of the runners, not allowing a more accurate characterization of the population participating in the respective studies.

Therefore, the main objectives of this study were to determine the foot strike patterns of recreational runners during typical training pace and to compare the personal and training characteristics between runners with different foot strike patterns.

4.3 METHODS

This is a cross-sectional study about foot strike pattern distribution in runners. Image acquisition and the fulfillment forms were conducted in places where people commonly run, such the main public parks of São Paulo city. Participants were selected according to convenience, and they were recruited before or after they went for their run. Participants needed to be older than 18 years of age and had to wear shoes during the evaluation, and those who reported any musculoskeletal injuries related to running in the moment of evaluation were not allowed to participate of the study. This study was approved by the Ethics Committee of Universidade Cidade de São Paulo.

514 runners accepted to participate of the study and fulfilled a formulary with information about individual characteristics (gender, age, weight and height) and running routine (predominant type of surface training, special insoles, weekly distance, coach utilization, years of practice and previous injury).

After they fulfilled the formulary, all participants were driven to the place where the image acquisition equipment was installed. This location included a 50-meter long track and a camera (Casio EXFX1) that was located halfway down the path for taking high-speed pictures (image acquisition frequency of 250 Hz). The camera was positioned on a tripod 15 cm high and 2 meters away from the running line (Figure 1). Photocells registered the speed, and the participants were instructed to run at a speed that they found comfortable. Participants ran twice to and from across the path for a total of 200 meters.

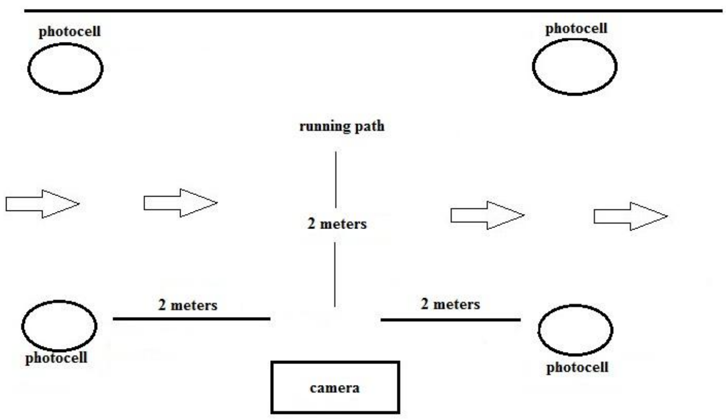

Figure 1. Schematic representation of the area for image acquisition

4.3.1 Image analysis

The videos with foot strike images were captured and then analyzed in a video analysis program (Kinovea 0.8.15). The four strides from all participants were analyzed from the lateral view of the foot. When the same runner demonstrated different patterns, the most frequently used stride was chosen. Foot strike pattern was defined by the part of the foot that collides with the ground first and fell into three classifications:[8] (1) rearfoot, when the runner lands with the heel; (2) midfoot, when the runner lands with the heel and ball of the foot simultaneously; and (3) forefoot, when the ball of the foot lands before the heel comes down. All foot strike patterns were analyzed by two evaluators, and when necessary, a third evaluator resolved discordances.

4.3.2 Foot strike pattern orientation

After the evaluation, some of the participants (n= 350, 67.8%) were asked by email if they had already received any type of orientation about foot strike. If yes, then they were asked was about the nature of the orientation. If a participant did not answer the email after a week, another email was sent. If the participant did not answer within another week, a third and final email was sent.

4.3.3 Evaluation of the posterior part of the shoes' height (H_{shoes})

The height of the posterior part of the shoes were realized for a portion of the sample (n = 160, 31.1%). The evaluation was done in the following way: in the first moment, the rule was positioned in the internal part of the shoe, which collected the internal height (H_{int}). Afterward, the external height was collected with a caliper rule (H_{ext}). The final result was the height of the posterior part of the shoe that corresponded with the difference between the internal and external ($H_{ext} – H_{int}$). The runners were evaluated in a standing position.

4.3.4 Comparative analysis of foot strike patterns

To compare the variables studied, the participants were divided in two groups: group I was composed of rearfoot strikers, whereas group II consisted of both midfoot and forefoot strikers, since there were small numbers of runners with these patterns.

4.3.5 Statistical analysis

For description of foot strike patterns during running and participants' characteristics we used a descriptive statically analysis. Evaluation of normality of continuous data (age, weight, body mass index, distance weekly, years of practice, average speed and H_{shoes}) was done with a curve symmetry analysis, and data with normal distribution were demonstrated in mean and standard deviation, while median and interquartile ranges were utilized for non-normal distribution. For comparative analysis, the Student-t test for independent samples was used for continuous variables with normal distribution, whereas the Mann-Whitney test was used for non-normal distribution data. For categorical data, the Chi-squared test was used. For all analyses, a 95% significance level was regarded as statistically significant. Intra-class and inter-class confiability were evaluated by Kappa coefficient and agreement percentage. The analyses were done in SPSS 17.0.

4.3.6 Sample size

Sample size of this study was estimated on 95% of rearfoot strikers based upon the pilot study, with a statistical precision of 2.5% and a significance level of 99%. The analysis suggested the evaluation of 506 runners. The authors decided to evaluate 514 runners to minimize possible losses in the gathering process and video analysis.

4.4 RESULTS

The foot strike patterns of 514 runners were analyzed in the present study. The description of runners' characteristics appears in Table 1. The majority of the runners were male (68.9%), with age of about 40 years old, a running distance of almost 25 km and a running practice time of five years.

Regarding the height of the posterior part of the shoes, the mean height was 4.5 cm (DP = 0.8) among the 160 shoes evaluated. 86% of runners were not using special insoles during evaluation, and the average speed was approximately 12 km/h. Most of the runners (83.3%) reported running on a hard surface, and almost half of the runners reported coach utilization.

Among the participants who answered the emailed question about foot strike pattern orientation, only 31.2% asserted that had not received any kind of orientation, whereas most of the participants who received orientation (59%), reported that they had been guided to adopt the rearfoot strike pattern. Only 13.7% reported that they had been guided to adopt a forefoot strike pattern, and the remaining 27.3% did not know what kind of orientation they had received.

About one third of the runners reported any previous musculoskeletal injury that forced them to stop running for some time. The location most affected by running related injuries was the knee (35.9%; n = 61), and the most frequent type of injury was muscle injury (21.2%; n = 36) and tendinopathy (16.5%; n = 28).

Table 1. Characteristics of the runners included in the study

Gender		**Insoles**	
Male	68.9% (354)	Yes	14% (72)
Female	31.1% (160)	No	86% (442)
Age (years)	41.7 (12.2)	**Coach utilization**	
Weigth (kg)	71.6 (12.7)	Yes	47.1% (242)
Heigth (m)	1.71 (0.09)	No	52.9% (272)
BMI (kg/cm²)	24.4 (3.0)	**Surface**	
Average Speed (km/h)	12.2 (2.4)	Hard	83.3% (428)
Km/week	24.8 (20.7)	Sand	6.4% (33)
Time of practice (years)*	5 (9)	Grass	0.6% (3)
Previous injury		Treadmill	9.7% (50)
Yes	33.1% (170)	**Foot strike pattern orientation**	
No	66.9% (344)	Yes	68.8% (241)
H_{shoes}	4.5 (0.8)	No	31.2% (109)

Continuous data with normal distribution are expressed in mean and standard deviation.
Continuous data with non-normal distribution are expressed in median and interquartil range*
Categorical data are expressed in percentage and number of runners.

Concerning foot strike pattern distribution, 489 (95.1%) of the runners were rearfoot strikers, 21 (4.1%) were midfoot strikers, and only four runners (0.8%) were forefoot strikers (Table 2). The evaluation method demonstrated a Kappa coefficient of 0.64 and agreement percentage of 96.7% for inter-evaluator confiability. For intra-evaluator confiability, the agreement percentage was 98.9% and the Kappa coefficient was 0.89.

Table 2. Foot strike patterns of runners		
	n	**%**
Rearfoot	489	95.1
Midfoot	21	4.1
Forefoot	4	0.8

Table 3 demonstrates the foot strike pattern distribution by gender. The proportion of the midfoot pattern was higher in male runners (5.1%) than in female runners (1.9%). More female runners (97.5%) had the rearfoot pattern than the male runners had (94.1%).

Table 3. Foot strike patterns distribution by gender

	Rearfoot	**Midfoot**	**Forefoot**
Male	94.1 (332)	5.1 (18)	0.8 (3)
Female	97.5 (156)	1.9 (3)	0.6 (1)

All data were expressed in percentage and numbers of runners

When the authors analyzed the comparison of variables between group I (rearfoot) and group II (midfoot and forefoot), no statistically significant differences between groups were noted for any variable (table 4).

Table 4. Comparison of the runners' characteristics between foot strike patterns.

	Group I (Rearfoot)	Group II (Midfoot and Forefoot)	p
Gender			0.094
Male	68.1% (333)	84% (21)	
Female	31.9% (156)	16% (4)	
Age (years)	41.7 (12)	41.2 (16.2)	0.855
Weigth (kg)	71.6 (12.7)	71.9 (13.6)	0.932
Heigth (m)	1.70 (0.1)	1.74 (0.1)	0.105
BMI (Kg/cm²)	24.4 (2.3)	23.6 (3)	0.191
Average speed (km/h)	12.2 (2.3)	13.1 (3.5)	0.075
Distance (km/week)	24.4 (20.7)	24.6 (17.9)	0.091
Time of practice (years)†	5 (9)	5 (12)	0.421
H_{shoes} (cm)	4.5 (0.8)	4.2 (0.8)	0.493
Previous injury			0.907
Yes	33.1% (162)	32% (8)	
No	66.9% (327)	68% (17)	
Insoles			0.375
Yes	14.3% (70)	8% (2)	
No	85.7% (419)	92% (23)	
Coach Utilization			0.185
Yes	46.4% (227)	60% (15)	
No	53.6% (262)	40% (10)	
Surface			0.100
Hard	83.2% (407)	84% (21)	
Sand	6.3% (31)	8% (2)	
Grass	0.4% (2)	4% (1)	
Treadmill	10% (49)	4% (1)	

Continuous data are expressed in mean and standard deviation, except o time of practice† that is expressed in median and interquartil range.

All categorical data are expressed in percentage and numbers of runners.

4.5 DISCUSSION

The results of this study demonstrated that almost all runners were rearfoot strikers (95.1%), whereas only four runners (0.8%) were forefoot strikers. Male runners had a higher proportion of midfoot strikers in comparison with female runners. No statistical differences were noted between the rearfoot strikers group and midfoot and forefoot group with regards to personal and training characteristics.

Concerning the foot strike patterns of runners, the results of the present study differ from the results of Larson et al,[11] Kerr et al[9] and Hasegawa et al,[7] who found that 88%, 80% and 75% of their participants were rearfoot strikers, respectively. This difference can be explained by the characteristics of our sample that was comprised of recreational runners who ran at a lower average speed (12.2 km/h) than did the half elite marathoners studied by Hasegawa et al[7] (17.7 to 19.6 km/h), and runners from Kerr et al[9] (12,4 a 19,9 km/h). As compared with Larson et al, [9] in which participants ran with a pace around 11 km/h, it was noted that the difference about rearfoot strikers' rate was smaller.

The second factor that can explain this lower percentage of rearfoot strikers in these studies[7, 9] is the low frequency of image acquisition that they used (60 Hz and 120 Hz). When the frequency of image acquisition is low, the evaluators can miss the exact moment of initial foot contact, since a smaller amount of frames is available. Thus, an erroneous interpretation of foot strike classification can occur, principally among rearfoot strikers that can be classified improperly as midfoot strikers. The accuracy of the evaluation of foot strike is directly related to the increase in image acquisition frequency.[12]

The foot strike patterns' distribution by gender showed a higher percentage of rearfoot strikers in female runners (97.5%) than in male runners (94.1%), and a higher percentage of male midfoot strikers (5.1%) than female midfoot strikers (1.9%). This finding is similar to the results from Hasegawa et al.[7] Despite this difference in foot strike patterns between genders, researchers who studied biomechanical differences between male and female runners found no significant differences at the ankle, foot joint or the knee position during the foot's initial contact during running.[13, 14]

A comparison between foot strike patterns (Table 4) was undertaken to verify the hypothesis that significant differences, especially in runners' speed and coach utilization, would exist among different foot strike patterns. However, no significant differences were found among foot strike patterns. Although differences were not significant, rearfoot strikers demonstrated a lower speed (12.2 km/h) than did midfoot and forefoot strikers (13.1 km/h). Thus, there might exist a threshold of speed that differentiates rearfoot strikers that are normally slower from midfoot and forefoot runners. About running coach, the participants usually reported that they were guided to adopt rearfoot pattern, since their running coaches advocates these pattern as the 'correct' way to run, even though studies show that midfoot and forefoot strikes attenuate the impact forces during running.[8, 15-19]

The authors also believe that the type of shoe used by runners can induce foot strike pattern. Over time, shoe companies have increasing thickness and cushion in the posterior part of shoes. This cushioning gives a higher sensation of comfort, furthering use of the rearfoot pattern. The results of this study demonstrate that the mean height of the posterior part of the shoes was 4.5cm, affirming the runners' preference for shoes with more cushioning in posterior part. It is important to note, however, that no evidence suggests that this kind of shoe is efficient at preventing running injuries.[20, 21]

One of the limitations of this study was the inconsistent timing of the evaluations (before or after running practice). We can ask if fatigue effects could change foot strike patterns, even no studies had evaluated this issue. Another limitation is due the smaller numbers of runner that were evaluated about the posterior part of the shoes' height and foot strike pattern orientation.

4.6 CONCLUSION

The foot strike patterns distribution of recreational runners demonstrated that almost all runners are rearfoot strikers. There are no statistical differences between rearfoot strikers when compared with midfoot and forefoot strikers for all personal and training characteristics.

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- CAPÍTULO 5-

CONSIDERAÇÕES FINAIS

O objetivo desta dissertação de mestrado foi abordar o tema "padrão de aterrissagem do pé durante a corrida", já que nos últimos anos vem aumentando o interesse da comunidade científica da área sobre este assunto. Os estudos realizados nesta dissertação contribuem com os pesquisadores que trabalham com lesões na corrida, através do esclarecimento de alguns pontos importantes e relevantes para a área.

O estudo realizado no capítulo 2 trata-se de um estudo pioneiro, já que até o momento não foi possível encontrar revisões sistemáticas que abordem as características biomecânicas entre os padrões de aterrissagem durante a corrida. Os resultados desse estudo chamam atenção pelo fato de como a simples mudança do padrão de aterrissagem acarreta inúmeras mudanças cinemáticas, cinéticas e espaços-temporais na corrida. O conhecimento sobre as características biomecânicas entre os padrões de aterrissagem para os profissionais da área é importante no momento de orientar os corredores sobre que padrão adotar durante a corrida. Apesar do resultado da revisão demonstrar que o padrão de retropé gera valores de impacto vertical maior no momento do contato inicial em comparação, ainda não é possível afirmar qual o padrão é o mais adequado para prática da corrida e se a adoção de determinando padrão pode ajudar na prevenção de lesões musculoesqueléticas relacionada à prática desse esporte.

Os resultados dos capítulos 3 e 4 desta dissertação demonstraram que a grande maioria dos corredores possui o padrão de retropé, apesar da revisão sistemática demonstrar que o impacto sofrido pelos corredores é maior quando esse padrão é adotado. No estudo piloto (capítulo 3), 98,1% dos corredores apresentaram o padrão de retropé, 1,9% apresentaram o padrão de mediopé e nenhum corredor possuía o padrão de antepé. Já no estudo do capítulo 4, houve uma diminuição da porcentagem do padrão de retropé para 95,1%, enquanto que o padrão de mediopé foi encontrado em 4,1% dos corredores, e diferentemente do estudo do capítulo 3, quatro corredores (0,8%) apresentaram o padrão de antepé. Essa diferença quanto a distribuição do padrão de aterrissagem entre os estudos, pode se explicada pelo tamanho da amostra reduzido do capítulo 3, que trata-se de um estudo piloto. Acredita-se que o padrão de aterrissagem possa ser influenciado por alguns fatores, especialmente o uso de calçados e orientação que é passada aos corredores pelo profissionais da área (fisioterapeutas, educadores físicos e treinadores) que trabalham com corrida.

A partir dessa possível influência da orientação que os corredores recebem para a prática da corrida, os resultados dos estudos desta dissertação irão auxiliar os profissionais a elucidarem suas dúvidas a respeito das características relacionadas aos padrões de aterrissagem e quais os padrões podem representar uma proteção ao sistema musculoesquelético dos corredores. Desta forma, esses profissionais poderão orientar da melhor forma possível os corredores, já que atualmente a grande parte desses profissionais que trabalha com corredores recreacionais orientam seus corredores a adotar o padrão retropé, ajudando assim na promoção e prevenção das lesões relacionadas a corrida.

Alguns pontos ainda precisam ser estudados, e o principal deles é a possível associação entre o padrão de aterrissagem adotado e lesões na corrida. Futuras pesquisas através de delineamentos prospectivos são necessárias para comprovar essa possível associação, e também esclarecer qual o padrão que funcionaria como um fator de proteção ou fator de risco para as lesões relacionadas a esse esporte. O desenvolvimento dessas pesquisas ajudaria no propósito de diminuir substancialmente as taxas de lesão e somaria em futuras estratégias de prevenção de lesões nos corredores, promovendo assim a prática mais segura desta modalidade que tem milhares de adeptos em todo o mundo.

- MATERIAL SUPLEMENTAR –

Author instruction – The International SportMed Journal

Instructions for Authors – The British Journal of Sports Medicine

AUTHOR INSTRUCTIONS – THE INTERNATIONAL SPORTMED JOURNAL

The *International SportMed Journal* (ISMJ) is an electronically delivered, international, peer-reviewed journal for professionals with a primary interest in sports and exercise medicine, as well as exercise science. In addition to review articles (invited and submitted), the ISMJ publishes original research covering diagnostics, therapeutics and rehabilitation in healthy and physically challenged individuals of all ages and levels of sport and exercise participation (see types of articles below).

Manuscripts are welcomed from all countries, and may be submitted for consideration on the understanding that they have not been previously published elsewhere, either in print or electronically, that they are not under consideration by any other publisher, that Research Ethics Committee (Board) approval has been obtained, and that all potential conflicts of interest have been declared.

All manuscripts must be submitted in English, and because the ISMJ is an English-language journal, the English must be of an acceptable standard. If a manuscript is submitted by an author who does not have English as their first language, the manuscript may require editing before it is submitted. This can be done by an online service that offers editing of scientific language for non-English speakers **before** it is submitted to reviewers.

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Use the passive voice in writing (e.g. Six elite athletes were tested).

Spelling should be English, not American, e.g. aetiology, anaemia. Use s-spellings, rather than z-spellings, e.g. minimise, organisation.

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If in doubt, include both with the conventional units in parentheses. Temperature should be expressed in degrees Celsius, and time in terms of the 24-hour clock.

l. Acknowledgements

These should be made where appropriate, particularly any source of funding provided for the study, technical assistance, and intellectual contributions not associated with authorship.

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The authors are responsible for the accuracy and completeness of the references. These are to be numbered consecutively in the text in superscript, without brackets, in the order that they appear in the text. List all authors when there are three or fewer. If there are more than three, list the first three followed by, et al. The reference section should be inserted at the end of the text using the Vancouver style (see http://www.icmje.org), following the sample formats given below. Journal titles should be abbreviated according to the abbreviations approved by *Index Medicus (*http://www.nlm.nih.gov/tsd/serials/lji.html).

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Online journal article

2. Grant S, Corbett K, Todd K, *et al*. A comparison of physiological responses and rating of perceived exertion in two modes of aerobic exercise in men and women over 50 years of age. BJSM 2002; 36: 276-281. Available at URL: http://bjsm.bmjjournals.com/cgi/content/full/36/4/276

World Wide Web

3. International Federation of Sports Medicine (FIMS). Ventilatory muscle training in patients with chronic obstructive pulmonary disease (COPD). Available at: URL: http://www.fims.org/position statements. Accessed 30 September 2002.

Book

4. Antonaccio MJ. *Cardiovascular pharmacology*. New York: Raven Press, 1990. References to books should give the names of any Editors, and page numbers, where relevant. The page numbers follow the date of publication.

Chapter in book

5. Pedersen BK, Rohde T, Bruunsgard H. In: Pedersen BK (Ed). *Exercise immunology*. Austin, TX: RG Landes, 1997, pp. 89-111.

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• ***Methods:*** Describe in 1-2 paragraphs the methodology used to answer the research question. The following sub-headings are useful: subjects (or participants, patients), sampling, experimental procedure (including if any interventions), and main measures of outcome.

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Each author should include a short biography that includes academic title/degrees, affiliation, research focus, awards and societal affiliations, and previous publications of note (not more than 10 of the most recent).

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An outline of the article's background and rationale should be included, ending with a clear statement of the research question, where relevant.

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These should be concise and not contain repetition of the methods. Data in the text should not be replicated in the tables or figures or vice versa.

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13 Koziol-Mclain J, Brand D, Morgan D, et al. Measuring injury risk factors: question reliability in a statewide sample. Inj Prev 2000;**6**:148–50.

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14 Nagin D. General deterrence: a review of the empirical evidence. In: Blumstein A, Cohen J, Nagin D, eds. Deterrence and Incapacitation: Estimating the Effects of Criminal Sanctions on Crime Rates. Washington, DC: National Academy of Sciences 1978:95–139.

Book

15 Howland J. Preventing Automobile Injury: New Findings From Evaluative Research. Dover, MA: Auburn House Publishing Company 1988:163–96.

Abstract/supplement

16 Roxburgh J, Cooke RA, Deverall P, et al. Haemodynamic function of the carbomedics bileaflet prosthesis [abstract]. Br Heart J 1995;73(Suppl 2):P37.

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