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Effects of heel lifts on lower limb biomechanics and muscle function: A systematic review

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ABSTRACT

Background: Heel lifts, placed inside footwear are recommended for the management of numerous musculoskeletal conditions. Despite the potential therapeutic benefit of heel lifts, the mechanism(s) by which they exert their effects is unclear. The aim of this systematic review was to synthesise reported findings and summarise the effects of heel lifts on lower limb biomechanics and muscle function.
Research question: Do heel lifts affect lower limb biomechanics and muscle function during walking and running?
Methods: Electronic databases (MEDLINE, EMBASE, CINAHL, SPORTDiscus, AMED) were searched from inception to April 2018. Studies were included if they (i) included participants without a limb length discrepancy or neurological condition, (ii) evaluated the effect of bilateral heel lifts that were removable (attached to the participants' foot (barefoot) or inserted inside footwear) or an existing feature of a shoe, and (iii) assessed lower limb biomechanics or muscle function during walking or running in asymptomatic or symptomatic participants.
Results: A total of 23 studies (377 participants) were included. Study quality, assessed using a Modified Quality Index, ranged from 5 to 13 out of 15. A large number of biomechanical parameters were assessed, but few effects were statistically significant. The differences that were significant and had a large effect size are described below. In asymptomatic participants, heel lifts of 10 mm decreased duration of swing phase (standardised mean difference [SMD] = -1.3) and heel lifts of at least 5 cm decreased velocity (SMD = -0.93) during walking. In asymptomatic participants, heel lifts of 15 mm decreased maximum ankle dorsiflexion angle (SMD = -1.5) and heel lifts of 12 and 18 mm decreased gastrocnemius muscle tendon unit length (SMD = -0.96) during running. In participants with restricted ankle joint dorsiflexion, heel lifts of 6 and 9 mm increased medial gastrocnemius electromyography amplitude (SMD between 0.68 and 0.98) during walking. In participants with haemophilia, heel lifts of 9 mm increased ankle joint maximum range of motion (SMD = 1.6) during walking.
Significance: Heel lifts affect specific lower limb biomechanical and muscle function parameters during walking and running. The clinical relevance and potential therapeutic benefits of these effects needs further investigation.

1. Introduction

Heel lifts (inserts placed inside footwear to alter the foot into a more plantarflexed position), are recommended for the management of a number of musculoskeletal injuries of the lower limb including: Achilles tendinopathy [1,2], Achilles tenosynovitis [3–5], tendoachilles bursitis [1,4,6], calcaneal apophysitis [7], posterior leg muscle strains [8] and plantar heel pain [9,10]. Furthermore, heel lifts have been proposed to normalise lower limb biomechanics in people with lower limb length discrepancies [11,12] and limited ankle dorsiflexion [13,14]. However, the therapeutic benefits of heel lifts are equivocal as there are few controlled trials [15–17] that have specifically investigated their effectiveness for musculoskeletal conditions of the lower limb.

Despite the potential therapeutic benefit of heel lifts, the mechanism (s) by which they may exert their effects is unclear. Alterations in lower limb biomechanical characteristics, including temporo-spatial parameters, kinematics, dynamic plantar pressures, kinetics (ground reaction forces and joint moments) and muscle function are frequently

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speculated to be mechanisms by which heel lifts have therapeutic effects. Consequently, several studies have been performed that have investigated the effects of heel lifts on lower limb biomechanics [14,18–38].

Summarising and critiquing the literature and the results from these studies is now required to assist clinicians in their decision making process to use heel lifts as a therapeutic intervention. Therefore, the aim of the present study was to perform a systematic review of the existing literature to (i) identify, summarise and critique the existing literature investigating the effects of heel lifts on lower limb biomechanics and muscle function, and (ii) provide guidance for further research into this area.

2. Methods

This systematic review was developed and is reported according to the guidelines provided by the Preferred Reporting of Systematic Reviews and Meta-Analysis (PRISMA) [39].

2.1. Data sources

A literature search of CINAHL, MEDLINE (OVID), EMBASE, SPORTDiscus and AMED (OVID) electronic databases occurred from inception to April 2018. The search strategy used a combination of search terms derived from Medical Subject Headings (MeSH) and keywords specific to the research question (Table 1). Electronic searches were supplemented by screening reference lists of selected studies and communication with content experts.

2.2. Inclusion/exclusion criteria

Studies were included if they met the following criteria:

(i) experimental study of humans with a cross-sectional or longitudinal design (number of participants > 1);
(ii) compared bilateral heel lifts with no heel lift. The heel lift was removable (attached to the participants' foot (barefoot) or in-shoe) or an existing feature of a shoe designed to alter the foot and ankle into a more plantarflexed position;
(iii) participants were assessed when walking or running;
(iv) evaluated lower limb biomechanical parameters or muscle function.

Unpublished or non-peer reviewed articles, or studies that included participants with a neurological condition or lower limb discrepancy were excluded. Where the heel lift intervention did not meet the definition defined by this systematic review (stated above) or the shoe used had the potential to create instability (i.e. women's heeled dress/court shoe) the study was excluded [40,41].

2.3. Data extraction

All articles identified through the database search were downloaded into Endnote version X8 (Thomson Reuters, Philadelphia, PA) by a single author (CLR) and duplicates deleted. Titles and abstracts were independently screened for inclusion by two authors (CLR and GAW). If there was insufficient information within the title and abstract, the full text was obtained for evaluation. Disagreements between authors were resolved at a consensus meeting with a third author (SEM).

Two authors (CLR and AME) independently extracted relevant data. In studies using asymptomatic participants, data for the right lower limb only were included when studies provided a breakdown for both lower limbs to maintain independence of data [42]. In studies using symptomatic participants, data for the symptomatic side were extracted (or from the right side only if participants had bilateral symptoms). Missing data were requested from corresponding authors and were deemed unavailable after two unsuccessful attempts (no response).

2.4. Assessment of methodological quality

Two authors (CLR and JMT) independently assessed the methodological quality of each study using a modified version of the Quality Index tool, a validated tool [43] (see Table 2). Disagreements were resolved by discussion with a third author (SEM).

2.5. Data analysis

Data were categorised according to the heel lift height (up to 15 mm and 15 mm or greater), gait conditions analysed (running/walking, barefoot/in-shoe) and participants' health status (symptomatic/asymptomatic).

Means and standard deviations of the biomechanical parameters were extracted and standardised mean differences (SMDs) with 95% CIs calculated. The magnitude of the SMD was categorised as small (< 0.50), medium (0.50 to 0.79) or large (≥ 0.80) [44]. Meta-analyses were not performed due to large variability in study methods. Descriptive data provided via email correspondence [18] and extrapolation from published graphs [26,33,45] was required to complete some statistical analyses.

Table 1
Search strategy and results from each included database.

	Search term	MEDLINE[1,2]	CINAHL [1,2]	EMBASE[1,2]	SPORT Discus	AMED[2]
1	spatiotemporal	8,241	547	11,489	703	122,232
2	temporo-spatial	346	50	38,314	49	23,658
3	kinetic*	198,088	4,654	158,817	23,413	132,747
4	kinematic*	138,346	7,611	145,208	14,886	134,223
5	biomechanic*	163,044	16,219	117,873	52,502	40,590
6	electromyograph* OR EMG	71,995	8,912	79,619	13,865	2,671
7	muscle* OR muscle mechanic*	460,031	42,969	846,566	110,828	40,590
8	function OR activit*	2,916,655	308	3,407,282	270,270	51,015
9	motion OR range of motion	52,670	2,518	46,272	40,763	9,656
10	walk*	85,286	20,228	147,768	34,991	122,450
11	run*	89,012	11,841	129,897	128,158	120,324
12	gait OR gait analysis	39,167	9,403	66,359	15,227	130,705
13	S1 OR S2 OR S3 OR S4 OR S5 OR S6 OR S7 OR S8 OR S9 OR S10 OR S11 OR S12	3,580,904	86,632	4,352,550	529,724	175,788
14	heel lift* OR heel raise* OR heel pad* OR heel elevation* OR heel ortho* OR heel cushion* OR heel insert*	536	377	695	333	122
15	S13 AND S14	405	177	527	264	109

[1] Limit to humans.

Table 2
Modified Downs and Black Quality Index results, and inter-rater reproducibility for each item and total score.

Study	Reporting							
	1. Clear aim/objective	2. Outcome measures clearly described	3. Participant characteristics clearly described [m]	4. Interventions clearly described	6. Main findings clearly described	7. Estimates of the random variability reported	10. Actual probability values reported [m]	11. Participants representative of entire population [m]
Bird, 2003 [18]	1	1	1	1	1	1	2	1
Bonanno, 2011 [19]	1	1	1	1	1	1	2	1
Dixon, 1998 [22]	1	1	1	1	1	1	2	0
Dixon, 1999 [21]	1	1	0	1	1	1	2	0
Dixon, 2002 [20]	1	1	0	1	1	1	2	0
Farris, 2012 [23]	1	1	1	1	1	1	2	0
Hsi, 1999 [24]	1	1	1	1	1	1	2	1
Johanson, 2006 [14]	1	1	1	1	1	1	2	1
Johanson, 2010 [25]	1	1	1	1	1	1	2	0
Katoh, 1983 [26]	0	1	1	1	1	1	2	0
Lee, 1987 [33]	1	1	1	1	1	0	2	0
Low, 2015 [35]	1	1	1	1	1	1	2	0
Mestelle, 2017 [36]	1	1	1	0	1	1	2	0
Ramanathan, 2008 [27]	1	1	1	1	1	1	1	0
Ramanathan, 2008 [38]	1	1	1	1	1	1	2	0
Reinschmidt, 1995 [28]	1	1	1	1	1	1	2	0
Seuser, 1997 [29]	1	1	1	0	1	0	0	0
Valentini, 2009 [31]	1	1	1	1	1	1	1	0
Wang, 1994 [37]	1	1	0	1	1	1	1	0
Wearing, 2014 [34]	1	1	1	1	1	1	2	0
Wulf, 2016 [30]	1	1	1	1	1	1	2	0
Zhang, 2014 [32]	1	1	1	1	1	1	2	0
Zhang, 2016 [45]	1	1	1	1	1	1	2	0
Unweighted kappa coefficient	0.65	0.00*	0.47	1.00	0.00*	1.00	1.00	1.00
% agreement	100.0	100.0	92.9	100.0	100.0	100.0	100.0	100.0

Study	External validity	Internal validity			Selection bias	Power	
	13. Intervention(s) representative of those in clinical practice [m]	14. Attempt to blind participants to intervention	18. Appropriate statistical tests used	20. Accurate main outcome measures used	23. Participants randomised to intervention group	27. Adequately justified sample size [m]	Total (/15) (%)
Bird, 2003 [18]	0	0	1	1	1	0	12 (80)
Bonanno, 2011 [19]	1	0	1	1	1	0	13 (87)
Dixon, 1998 [22]	0	0	1	1	1	0	11 (73)
Dixon, 1999 [21]	0	0	1	1	0	0	9 (60)
Dixon, 2002 [20]	0	0	1	1	1	0	10 (67)
Farris, 2012 [23]	0	0	1	1	1	0	11 (73)
Hsi, 1999 [24]	1	0	1	1	1	0	13 (87)
Johanson, 2006 [14]	1	0	1	1	1	0	13 (87)
Johanson, 2010 [25]	1	0	1	1	1	1	13 (87)
Katoh, 1983 [26]	1	0	1	1	0	0	10 (67)
Lee, 1987 [33]	1	0	1	0	0	0	9 (60)
Low, 2015 [35]	1	0	1	1	0	0	11 (73)
Mestelle, 2017 [36]	1	0	1	1	0	1	11 (73)
Ramanathan, 2008 [27]	1	0	1	1	1	0	11 (73)
Ramanathan, 2008 [38]	1	0	1	1	1	0	12 (80)
Reinschmidt, 1995 [28]	1	0	1	1	1	0	12 (80)
Seuser, 1997 [29]	1	0	0	0	0	0	5 (33)

(*continued on next page*)

Table 2 (*continued*)

Study	External validity	Internal validity			Selection bias	Power	
	13. Intervention(s) representative of those in clinical practice m	14. Attempt to blind participants to intervention	18. Appropriate statistical tests used	20. Accurate main outcome measures used	23. Participants randomised to intervention group	27. Adequately justified sample size m	Total (/15) (%)
Valentini, 2009 [31]	0	0	1	1	0	0	9 (60)
Wang, 1994 [37]	0	0	1	1	0	0	8 (53)
Wearing, 2014 [34]	0	0	1	1	0	0	10 (67)
Wulf, 2016 [30]	1	0	1	1	1	1	13 (87)
Zhang, 2014 [32]	1	0	1	1	1	0	12 (80)
Zhang, 2016 [45]	0	1	0	1	1	0	11 (73)
Unweighted kappa coefficient	0.00*	1.00	1.00	0.67	1.00	1.00	ICC = 0.98 (0.94 to 0.99)
% agreement	100.0	100.0	100.0	92.9	92.9	100.0	

0 not reported or not satisfied, 1 reported and satisfied. *high agreement low kappa paradaox, m modified, 2 SMD and CI reported.

3. Results

3.1. Overview of study selection

Initially 1,483 citations were retrieved; 682 duplicates were removed so that 801 articles were assessed for inclusion. Seven hundred and seventy eight articles were excluded based on the title and abstract or full text review analysis (see Fig. 1). Three discrepancies [46–48] were identified during full text analysis and resolved with a consensus meeting where all three studies were excluded. A total of 22 studies [14,18–33,35–38,45] met the inclusion criteria and an additional study [34] was included after reference scanning resulting in the inclusion of 23 studies. Two studies [27,38] used the same data set and seven studies [21–24,27,31,37] were not included in statistical analyses due to missing data.

3.2. Characteristics of included studies

Table 3 shows the characteristics of the 23 included studies. There were a total of 377 participants with study samples ranging from 3 [22] to 36 [19] participants. Sixteen studies [18,20–23,27,28,30–36,38,45] analysed asymptomatic participants, three studies analysed participants with ‘plantar heel pain’ [19,24,26], one study also analysed participants with ‘plantar fascial pain’ [26], one study analysed participants with haemophilia [29] and two studies [14,25] analysed participants with limited ankle dorsiflexion. One study [37] analysed a group of participants with heel pain and asymptomatic participants. There was large variability in walking speed protocols during data collection. Eight studies instructed participants to walk at their natural/comfortable/usual speed [14,24,25,27,31,32,38,45], one study instructed participants to walk at a ‘free speed’ [26], mean walking or running speed was reported by twelve studies [19,20–23,28–30,33–36], one study [37] analysed participants at a speed specified by the researchers (walking at 3.5 km/hr, running at 10 km/hr) and one study did not specify how walking speed was determined [18]. Most running studies [20,21,23,36] used a rearfoot strike strategy, one study [22] used heel, midfoot and forefoot strike strategies, and one study [28] did not specify the foot strike strategy used.

3.3. Methodological quality of included studies

The methodological quality appraisal had high reproducibility (for all items kappa ≥ 0.47, percentage agreement ≥ 92.9; overall ICC = 0.98). Individual item and total scores of the modified Quality Index for included studies are shown in Table 2. Quality scores ranged from 5 (33%) to 13 (87%)/15. A large proportion of the studies (83%) [20–23,25–38,45] did not adequately describe participant recruitment (Item 11), or perform prospective sample size calculations (Item 27) (87%) [14,18–24,26–29,31–35,37–38,45] and eight studies (35%) [18,20–23,31,34,37] used an intervention or method that was not considered reflective of clinical practice (Item 13). The age of participants was not reported in five studies [20–22,29,37] and body weight and/or height was not reported in ten studies [20–22,26–29,31,37,38].

3.4. Effect of heel lifts on lower limb biomechanics

Supplementary files 1–10 summarise the effect of heel lifts on lower limb biomechanics and muscle function. Statistically significant findings are described below, and a pictorial summary of key findings is provided in Fig. 2.

3.5. Asymptomatic participants during walking

3.5.1. Temporo-spatial parameters: heel lifts up to 15 mm

Two studies [30,34] assessed temporo-spatial parameters with in-shoe heel lifts of 10 or 12 mm. Cadence, step width, step length,

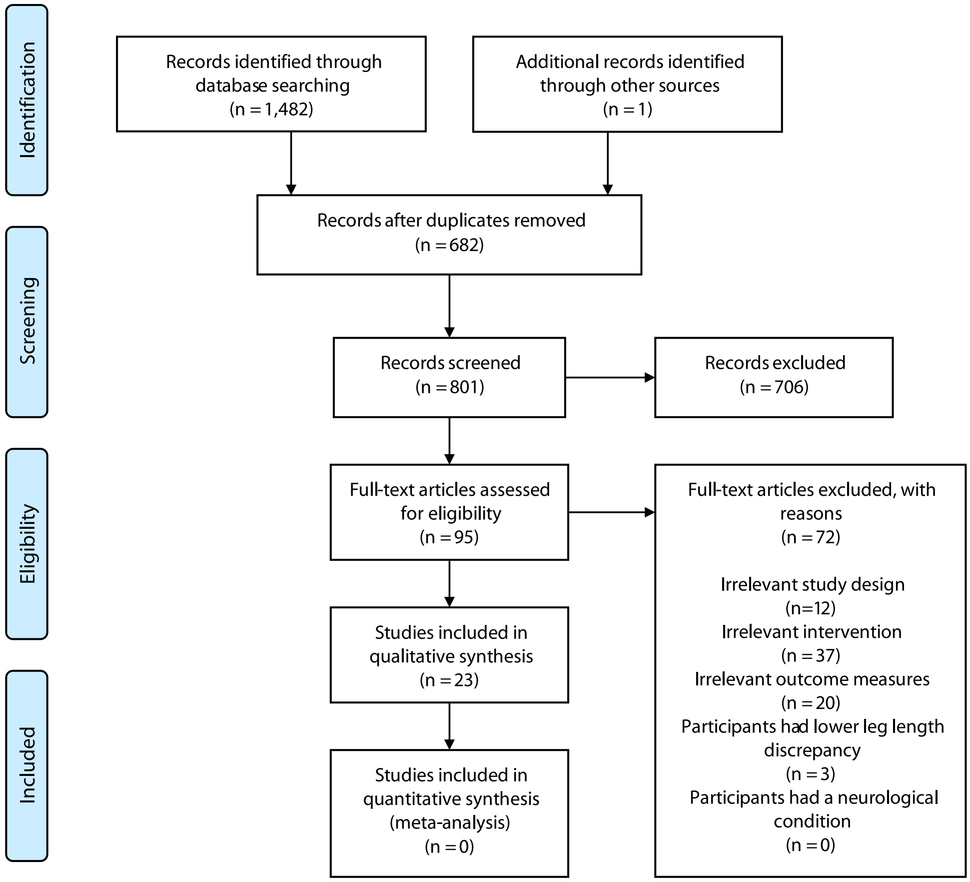

Fig. 1. Flow of studies through the review process.

duration of stance phase, duration of swing phase and velocity were assessed. In one study [34] heel lifts of 10 mm decreased the duration of swing phase (SMD -1.3, 95% CI -2.2 to -0.39, large effect) and the duration of single support (SMD -1.1, 95% CI -2.0 to -0.26, large effect), and increased the duration of double support (SMD 1.2, 95% CI 0.28–2.0, large effect) (Supplementary file 1).

3.5.2. Temporo-spatial parameters: heel lifts 15 mm or greater

One study [26] assessed the effect of heel lifts that were an existing feature of a shoe (reported to be at least 5 cm) on temporo-spatial parameters (cadence, step width, step length, duration of stance phase, duration of swing phase and velocity). Step width (SMD -1.1, 95% CI -2.1 to -0.16, large effect) and velocity (SMD -0.93, 95% CI -1.8 to -0.04, large effect) decreased with heel lifts [26] (Supplementary file 1).

3.5.3. Kinematic parameters: heel lifts of any height

No studies investigated the effect of heel lifts on lower limb kinematics (Supplementary file 2).

3.5.4. Kinetic parameters: heel lifts up to 15 mm

Five studies [20,23,30,34,35] investigated the effect of in-shoe heel lifts of 7.5–12 mm on lower limb kinetics. In one study [30] maximum ground reaction force decreased at the hindfoot (SMD -1.0, 95% CI -1.9 to -0.18, large effect) with in-shoe heel lifts of 12 mm (Supplementary file 3).

3.5.5. Kinetic parameters: heel lifts 15 mm or greater

No studies investigated the effect of heel lifts greater than 15 mm on lower limb kinetics (Supplementary file 3).

3.5.6. Muscle function parameters: heel lifts up to 15 mm

No studies investigated the effect of heel lifts greater than 15 mm on lower limb muscle function (Supplementary file 4).

3.5.7. Muscle function parameters: heel lifts 15 mm or greater

Two studies [18,33] investigated the effect of heel lifts on function of gastrocnemius, tibialis anterior and gluteus medius. In one study [33] tibialis anterior peak activity increased with heel lifts of 19, 38 and 57 mm adhered to the foot (barefoot) (SMD between 0.83 and 1.08) (Supplementary file 4).

3.5.8. Plantar pressure parameters: heel lifts up to 15 mm

One study [38] investigated the effect of heel lifts on plantar pressures during walking with 6 different in-shoe heel lifts with heights ranging from 5 to 10 mm. Peak pressure at the heel decreased with heel lifts of 9 mm and two heel lifts with unspecified heights (SMD between -0.83 and −1.1) (Supplementary file 5).

3.5.9. Plantar pressure parameters: heel lifts 15 mm or greater

Two studies [32,45] investigated the effect of in-shoe heel lifts on plantar pressures; one study [32] with 5 different heel lifts that varied in height and hardness (16 mm/*medium*, 25 mm/*medium*, 34 mm/*soft*, 34 mm/*medium*, 34 mm/*hard*) and one study [45] using a 25 mm heel lift.

At the rearfoot for all heel lift conditions, both studies [32,45] found peak pressure decreased (SMD between -2.0 and -1.2). In, one study [32] rearfoot contact area decreased (SMD -0.88, 95% CI -1.5 to -0.31, large effect) and pressure time integral (SMD 1.5, 95% CI 0.87–2.1, large effect) increased in 34 mm/hard heel lifts.

At the midfoot, one study [32] found peak pressure (SMD -1.4, 95% CI -2.1 to -0.83, large effect) and pressure time integral (SMD -1.2, 95%

Table 3
Characteristics of included studies assessing the effect of heel lifts on lower limb biomechanics.

Study	Sample					Gait conditions analysed		
	Symptomatic	Sample size (n)	% male	Age (mean (SD)) years	Mean (SD) body mass (kg); height (cm); BMI	Walking	Running	Instructed distance/ speed
Bird, 2003 [18]		13	46	22.3 (3.4)	71.6 (7.8); 173.1 (7.3); NS	●		NS
Bonanno, 2011 [19]	PHP	36	67	71 (6.9)	81.4 (13.1); 170 (8.0); 28.7 (4.8)	●		8 m
Dixon, 1998 [22]		3	0	NS	54.7 (0.5); NS; NS		●	3.8 m/s
Dixon, 1999 [21]		8	0	NS	NS; NS; NS		●	3.8 m/s
Dixon, 2002 [20]		7	0	NS	55.6 (3.5); NS; NS		●	15 m
Farris, 2012 [23]		10	0	20 (1.0)	63.9 (10.8); 170 (1.0); NS		●	10 m
Hsi, 1999 [24]	PHP	22	36	48 (14.0)	63 (9.0); 160 (8.0); NS	●		12 m
Johanson, 2006 [14]	5°	26	19	25.2 (5.9)	65.5 (9.2); 170 (8.4) NS	●		NS
Johanson, 2010 [25]	5°	24	50	26 (SEM:5)	SEM: 71 (5.0); 170 (2.0) ;NS	●		NS
Katoh, 1983 [26]	PHPF	P: 9 F*	54	26 to 62	NS	●		NS
Lee, 1987 [33]		13	100	Range 16 to 48	69 (NS); 170 (NS); NS	●		88 s/min
Low, 2015 [35]		9	100	23 (3.7)	83.4 (5.8); NS; NS		●	15 m, 3.8 m/s
Mestelle, 2017 [36]		16	0	21. (1.6)	61.3 (9.6); 169.8; NS		●	20 m, 3.46 m/s
Ramanathan, 2008 [27]		35	80	34.6 (NS)	NS	●		10 m
Ramanathan, 2008 [38]		35	80	34.6 (NS)	NS	●		10 m
Reinschmidt, 1995 [28]		5	100	31.6 (6.8)	72.7 (6.2); NS; NS		●	4.6 m/s
Seuser, 1997 [29]	H	6	NS	NS	NS	●		2 km/hr
Valentini, 2009 [31]		14	36	26.5 (5.21)	NS; 170 (4.1); 18.5 to 34.9	●		1 m
Wang, 1994 [37]	PHP	22	50	26 to 48 years (NS)	NS	●	●	walk: 3.5 km/hr, run 10 km/hr
Wearing, 2014 [34]		12	100	31 (9.0)	81 (16.9); 180 (6.0); NS	●		3.4 km/hr
Wulf, 2016 [30]		12	100	31 (9.0)	1.8 (0.06); 81 (16.9); NS	●		NS
Zhang, 2014 [32]		17	100	21.6 (1.2)	59.0 (4.7); 1.7 (2.9); NS	●		8 m
Zhang, 2016 [45]		20	100	22.4 (0.9)	57.5 (9.5); 168.0 (2.9); NS	●		8 m

Study	Gait conditions analysed		Heel lift specifications		Footwear condition(s)				
	Overground	Treadmill	Height (mm)	Material(s)	Barefoot	Cam walker	Athletic footwear	Flat footwear	Casual footwear
Bird, 2003 [18]	●		20	EVA	●				
Bonanno, 2011 [19]	●		6, 10	EVA; PU; Si				●	
Dixon, 1998 [22]	NS		7.5, 15	EVA	●				
Dixon, 1999 [21]	●		7.5, 15	EVA	●				
Dixon, 2002 [20]	●		7.5, 15	EVA	●				
Farris, 2012 [23]	●		12, 18	EVA	●				
Hsi, 1999 [24]	●		NS	Si				●	
Johanson, 2006 [14]	●		6, 9	NS			●		
Johanson, 2010 [25]	●		6, 9	NS			●		
Katoh, 1983 [26]	●		NS	PU; PE					●
Lee, 1987 [33]	●	●	19, 38, 57	PU					●
Low, 2015 [35]	●		10	Sorbothane gel			●		
Mestelle, 2017 [36]	●		11	NS			●		
Ramanathan, 2008 [27]	●		NS (Z, M);10 (S); 5 (P); 9 (A, B)	Si			●		
Ramanathan, 2008 [38]	●		NS (Z, M);10 (S); 5 (P); 9 (A, B)				●		

(continued on next page)

Table 3 (*continued*)

Study	Gait conditions analysed		Heel lift specifications		Footwear condition(s)				
	Overground	Treadmill	Height (mm)	Material(s)	Barefoot	Cam walker	Athletic footwear	Flat footwear	Casual footwear
Reinschmidt, 1995 [28]	●		21 (C), 24, 27, 30, 33	EVA			●		
Seuser, 1997 [29]		●	NS	Si					
Valentini, 2009 [31]	●		10, 20	Cork	●				
Wang, 1994 [37]		●	NS	PE, PU,					
Wearing, 2014 [34]		●	10	EVA			●		
Wulf, 2016 [30]		●	12	EVA			●		
Zhang, 2014 [32]	●		S 34 M 16, 25, 34 H 34	PE				●	
Zhang, 2016 [45]	●		25	EVA				●	

Study	Footwear condition(s)		Biomechanical parameter(s) reported				
	Participants' footwear	Temporo-spatial	Kinematics	Kinetics	Muscle function	Plantar pressures pressure	Miscellaneous parameters
Bird, 2003 [18]					●		
Bonanno, 2011 [19]						●	
Dixon, 1998 [22]			●	●		●	
Dixon, 1999 [21]			●	●		●	
Dixon, 2002 [20]		●		●			
Farris, 2012 [23]			●	●		●	●
Hsi, 1999 [24]						●	
Johanson, 2006 [14]		●	●				
Johanson, 2010 [25]	●		●		●		
Katoh, 1983 [26]		●	●	●			
Lee, 1987 [33]					●		
Low, 2015 [35]			●	●			
Mestelle, 2017 [36]		●	●	●			
Ramanathan, 2008 [27]						●	
Ramanathan, 2008 [38]						●	
Reinschmidt, 1995 [28]				●			
Seuser, 1997 [29]	●	●		●			
Valentini, 2009 [31]		●	●	●		●	
Wang, 1994 [37]	●			●			
Wearing, 2014 [34]		●					●
Wulf, 2016 [30]				●			●
Zhang, 2014 [32]		●		●		●	
Zhang, 2016 [45]							

NS not specified in the study and/or unable to obtain results upon contact corresponding author, PHP plantar heel pain, 5° less than 5 ° dorsiflexion (limited ankle dorsiflexion), F plantar fasciitis, H haemophilia, W women, M men, * 3 participants with heel lift and 7 with control, A Algeos, P Profoot, Z Zanni, M Minigrip, B Baufield, S Silipos, C Control, M Medium, S Soft, H Hard. EVA Ethylene-vinyl acetate, PE Polyethylene (plastic), PU Polyurethane (rubber), Si Polysiloxane (silicone), PHP patients heel cup vs no heel cup, PF patients with heel cup vs no heel cup, SEM standard error of the mean.

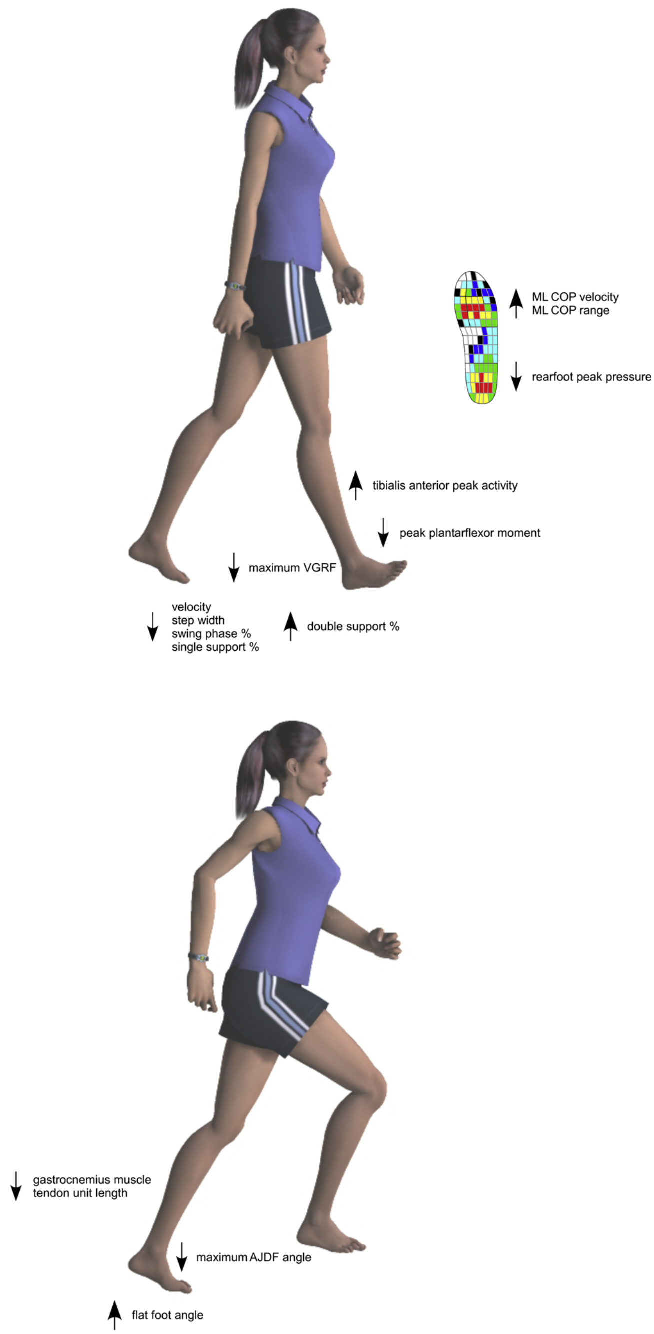

Fig. 2. Pictorial summary of key findings.

CI -0.18 to -0.58, large effect) to decrease for heel lifts: 34 mm/*hard*. The same study [32] also found a significant decrease in contact area (SMD between -3.7 and -0.67) for all heel lift conditions. In the other study [45] contact area (SMD 2.4, 95% CI 1.52–3.17, large effect) and peak pressure (SMD 0.68, 95% CI 0.04–1.32, medium effect) increased with 25 mm heel lifts.

At the forefoot, one study [32] found a significant increase in peak pressure for all 34 mm heel lift conditions (SMD between 0.66 and 0.82) and contact area for the heel lift 16 mm/*medium* (SMD 0.75, 95% CI 0.19–1.3, medium effect). Additionally, the same study found a significant increase in the pressure time integral (SMD between 0.96 and 2.2) and range of velocity of ML-COP during forefoot contact phase (SMD between 0.69 and 1.3) [32]. In another study [45] the percentage of force-time integral decreased at the forefoot (SMD -0.66, 95% CI -1.30 to -0.02, medium effect).

One study [32] found the velocity of medial-lateral centre of pressure (ML-COP) (all three 34 mm heel lift conditions) (SMD between 0.99 and 2.0) and range of ML-COP (all heel lift conditions) to increase during flat foot phase (SMD between 0.83 and 1.9) (Supplementary file 5).

3.5.10. Miscellaneous biomechanical parameters

Two studies [30,34] assessed the effect of heel lifts on miscellaneous lower limb biomechanical parameters (including acoustic and ultrasonic velocity of the Achilles tendon and peak Achilles tendon strain) and no statistically significant effects were found (Supplementary file 6).

3.6. Asymptomatic participants during running

3.6.1. Temporo-spatial parameters: heel lifts up to 15 mm

One study [36] investigated the effect of 11 mm in-shoe heel lifts on temporo-spatial data, and found initial contact centre of pressure location as a percentage of foot length to increase (SMD 0.89, 95% CI 0.16–1.6, large effect) (Supplementary file 1).

3.6.2. Temporo-spatial parameters: heel lifts 15 mm or greater

No studies investigated the effect of heel lifts on temporo-spatial data (Supplementary file 1).

3.6.3. Kinematics: heel lifts up to 15 mm

Two studies [21,36] investigated the effect of heel lifts of 7.5 and 11 mm adhered to the foot (barefoot) and in-shoe respectively on lower limb kinematics, however no statistically significant effects were found (Supplementary file 2).

3.6.4. Kinematics: heel lifts 15 mm or greater

One study [21] investigated the effect of heel lifts of 15 mm adhered to the foot (barefoot) on lower limb kinematics. A significant decrease in maximum ankle dorsiflexion angle (SMD -1.5, 95% CI -2.7 to -0.24, large effect) [21] and significant increase in flat foot angle (inclination of the foot with the horizontal at the time of minimum foot angular velocity) was found (SMD 1.7, 95% CI 0.42–3.0, large effect) [21] (Supplementary file 2).

3.6.5. Kinetics: heel lifts up to 15 mm

One study [36] investigated the effect of 11 mm in-shoe heel lifts on lower limb kinetics, however no statistically significant effects were found (Supplementary file 3).

3.6.6. Kinetics: heel lifts 15 mm or greater

Three studies [20,23,28] investigated the effect of heel lifts on lower limb kinetics during running with heel lifts 15–33 mm. No statistically significant effects were found (Supplementary file 3).

3.6.7. Muscle function: heel lifts of any height

No studies investigated the effect of heel lifts on lower limb muscle function (Supplementary file 4).

3.6.8. Plantar pressures: heel lifts of any height

No studies investigated the effect of heel lifts on plantar pressures (Supplementary file 5).

3.6.9. Miscellaneous biomechanical parameters

One study [23] assessed the muscle tendon unit length change of gastrocnemius using heel lifts of 12 and 18 mm adhered to the foot (barefoot). There was a significant decrease in length for the 12 mm (SMD -0.96, 95% CI -1.9 to -0.02, large effect) and 18 mm (SMD -0.96, 95% CI -1.9 to -0.02, large effect) heel lifts [23] (Supplementary file 6).

3.7. Effect of heel lifts on lower limb biomechanics in symptomatic participants or individuals with limited ankle dorsiflexion

3.7.1. Plantar heel pain (localised heel tenderness)

Three studies [19,24,26] investigated the effect of heel lifts on lower limb biomechanics in participants with plantar heel pain during walking. In one study [19], statistically significant decreases in (i) maximum force (SMD between -0.99 and -0.84), (ii) peak pressure (SMD between -0.71 and -0.49) and (iii) contact area (SMD between -0.97 and -0.73) [19] in the midfoot during walking were found for heel cups of 7 mm, heel pads of 6 mm and in-shoe heel lifts of 6 mm at the hindfoot, midfoot and forefoot (Supplementary file 7) [19].

3.7.2. Plantar fascia pain (pain with passive toe dorsiflexion)

One study [26] investigated the effect of heel cups of 7 mm on temporo-spatial, kinematic and kinetic variables in participants with ‘plantar fascia pain’ during walking. No statistically significant findings were found (Supplementary file 8).

3.7.3. Limited ankle dorsiflexion

Two studies [14,25] investigated the effect of in-shoe heel lifts of 6 mm, 9 mm and 12 mm on temporo-spatial, kinematics (peak knee angle, maximum ankle dorsiflexion angle and total ankle motion) and muscle function during walking in participants with limited ankle dorsiflexion.

Statistically significant effects were found in one study [25] for muscle function parameters, where in-shoe heel lifts of 6 mm and 9 mm increased medial gastrocnemius EMG amplitude from (i) heel strike to heel-off (SMD between 0.95 and 0.98); and (ii) heel off to toe-off (SMD 0.68, 95% CI 0.09 to 1.3, medium effect) for 9 mm heel lifts only (Supplementary file 9).

3.7.4. Haemophilia

One study [29] investigated effect of 9 mm in-shoe heel lifts on kinematic parameters during walking in participants with haemophilia. There was a significant increase in ankle joint maximum range of motion (SMD 1.6, 95% CI 0.23–3.0, large effect), maximum angular velocity of the subtalar joint (SMD 1.3, 95% CI 0.01–2.6, large effect) and ankle joint (SMD 2.0, 95% CI 0.49–3.5, large effect). Further, a large increase in maximum acceleration of the ankle joint (SMD 1.7, 95% CI 0.28–3.07, large effect) was found [29] (Supplementary file 10).

4. Discussion

The aim of this systematic review was to identify, critique and synthesise findings from the existing literature investigating the effects of heel lifts on lower limb biomechanics and muscle function to provide guidance for therapeutic use of this intervention and future research. This review identified 23 studies [14,18–38,45] that evaluated the effect of heel lifts on temporo-spatial, kinematic, kinetic, muscle function and plantar pressure parameters during walking and running in both asymptomatic and symptomatic participants. There were a large number of parameters investigated but relatively few effects were statistically significant. However, the majority of statistically significant effects were large.

The height (5–57 mm), material (polyethylene, polyurethane, polysiloxane, cork and plastic) and density (soft, medium and hard) of the heel lifts used in the studies included in this review varied considerably. In addition, although most studies used heel lifts placed inside participants’ footwear there were studies that adhered the heel lifts to the participants’ feet. This large methodological variation made meta-analysis unfeasible and made comparison of results across studies difficult.

4.1. Methodological quality

There was large variability in the methodological quality of the included studies. Quality Index scores ranged from five to 13 out of 15. Few studies [14,18,19,24] adequately described participant recruitment (item 11). Further, 10 studies [20–22,26–29,31,37,38] did not report all of the characteristics of their participants (such as age, sex, height, and mass). These two limitations impede the generalisability of the studies’ findings. In addition, few studies [25,30,36] performed prospective sample size calculations (item 27) so it is possible that many studies were underpowered to detect statistically significant effects.

4.2. Effect of heel lifts on lower limb biomechanical parameters in asymptomatic participants

4.2.1. Temporo-spatial parameters

There were inconsistent findings across the three studies [26,30,34] that evaluated the effect of heel lifts on temporo-spatial parameters during walking. This may be due to the variation of heel lift heights (10–50 mm) used and the surface used for gait analysis (overground and treadmill). Swing phase duration decreased using a 10 mm heel lift on a treadmill, and velocity and step width decreased with use of a heel lift > 50 mm during walking. However, the clinical significance of these findings is questionable as the heel lift height and/or gait condition (of at least 50 mm and treadmill) that was used in these studies is not commonly used in clinical practice. Interestingly, only one study [36] assessed the effect of heel lifts on temporo-spatial parameters during running and found only one statistically significant effect. Initial contact centre of pressure location as a percentage of total foot length increased, creating an anterior shift in initial centre of pressure. Taken together, the effect of heel lifts on temporo-spatial parameters during walking and running requires further research.

4.2.2. Kinematics

There were no studies that investigated the effect of heel lifts on lower limb kinematics during walking, and only two studies [21,36] evaluated the effect of heel lifts during running. Heel lifts (15 mm) increased ankle dorsiflexion during flat foot phase and decreased maximum ankle joint dorsiflexion during running (i.e. moved the foot into a more plantarflexed position). These findings suggest that heel lifts may be useful in the management of disorders of the Achilles tendon and posterior tissues of the lower leg where the aim is to reduce strain on these structures [50,51]. This is supported by two previous studies [16,17] that demonstrated heel lifts to be effective in reducing pain [17] and disability [16] associated with calcaneal apophysitis. However, further well-designed clinical trials using patient reported outcome measures are required to confirm this finding for other musculoskeletal conditions of the lower limb.

4.2.3. Kinetics

Seven studies [20,23,28,30,34–36] were identified that evaluated the effect of heel lifts on lower limb kinetics during walking and running. However, only one statistically significant effect was found: a decrease in maximum ground reaction force (total foot impulse). These findings suggest that heel lifts do not affect lower limb kinetics. However, it is possible that the lack of significant findings is the result of the studies being underpowered, since five of these studies [20,23,30,34,35] did not perform prospective sample size calculations. Future studies that use kinetic outcomes that are clinically relevant need to be performed in appropriately powered studies.

4.2.4. Electromyography

Two studies [18,33] compared EMG amplitude and onset of a limited number of muscles of the lower limb (i.e. gluteus medius, gastrocnemius, tibialis anterior) during walking in asymptomatic participants with heel lifts 19–57 mm. One of the studies [33] found an increase in activation of tibialis anterior. This finding suggests that heel lifts could potentially increase the risk of overuse injury of the dorsiflexor muscles of the ankle joint. However, well-designed clinical trials that measure adverse events are required to confirm this finding.

4.2.5. Plantar pressures

Three studies [32,38,45] investigated the effect of five different heel lift conditions on plantar pressures (including peak pressure, contact area and pressure time integral and percentage of force-time integral for the rearfoot, midfoot and forefoot) in asymptomatic participants during walking. Rearfoot peak pressure was the only variable to show a consistent decrease across all studies [32,38,45]. One of the studies [32] also found a large increase in the range of ML-COP in all heel lift conditions during flat foot phase and velocity of ML-COP for all 34 mm heel lifts that were assessed during flat foot phase and forefoot contact. The inconsistent findings across the heel lift conditions suggest that heel lift height and hardness may affect plantar pressures.

4.2.6. Miscellaneous biomechanical parameters

Three studies [23,30,34] were identified that assessed miscellaneous lower limb biomechanical parameters during walking [30,34] and running [23] in asymptomatic participants with few statistically significant effects. However, the muscle tendon unit length of gastrocnemius decreased when running in a 12 mm and 18 mm heel lift. When these effects are considered along with the observed lower limb kinematic effects, these findings support the use of heel lifts for the management of conditions of the Achilles tendon and posterior lower leg where the aim is to reduce strain on these structures [52]. However, well-designed clinical trials are required to confirm this finding.

4.2.7. Symptomatic participants or those individuals with limited ankle dorsiflexion

Although heel lifts are recommended as an intervention for a number of lower limb injuries, only six studies [14,19,24–26,29] assessed symptomatic participants or those with abnormal biomechanics. Plantar heel pain was the most commonly studied condition [19,24,26]. For participants with plantar heel pain, only one study [19] included a variable clinically relevant to the pathology (i.e. peak pressure and contact area at the rearfoot). In this study, heel lifts did not affect rearfoot plantar pressure, which suggests that heel lifts may not be indicated for treatment of plantar heel pain. Studies that recruited populations with limited ankle dorsiflexion found medial gastrocnemius EMG amplitude to increase when using heel lifts of 6 and 9 mm [14,25]. These findings did not occur in asymptomatic populations suggesting that the presence of lower limb pathology may be a factor that influences the biomechanical effect of heel lifts. These findings also highlight that future studies should evaluate symptomatic participants so that the findings are more relevant to the clinical setting. For participants with haemophilia, heel lifts increased maximum angular velocity of the subtalar and ankle joint and increased maximum angular acceleration and range of motion of the ankle joint [29]. However, the clinical importance of these effects is unclear.

4.2.8. Limitations

The findings of this systematic review need to be considered in light of a number of limitations. First, although this review aimed to bring together all of the relevant studies in this area, knowledge obtained is not complete. There was significant variation in the methods (such as sample size, the type of heel lifts used, biomechanical parameters analysed) across the included studies limiting the ability to perform meta-analysis. For running studies, a rearfoot strike strategy was predominantly used, so the influence of different foot strike strategies requires further investigation. Second, the quality of included studies was highly variable. Third, none of the included studies allowed for habituation, so the longer-term effects of heel lifts remain unknown. Fourth, there were no studies that investigated the effect of heel lifts on lower limb kinematics during walking, or muscle function or plantar pressure parameters during running. Finally, although heel lifts are commonly used for the management of lower limb musculoskeletal disorders, there were few studies that included participants with lower limb pathology. Notably, there were no studies that included participants with disorders of the Achilles tendon or posterior lower leg.

4.2.9. Recommendations for future research

Given the limitations of the current literature, there is an obvious need for high quality research in this area. Specifically, future studies need to (i) include larger sample sizes with an *a priori* sample size calculation, (ii) ensure that the heel lift intervention (specifying the height, pitch and density) and testing footwear used is adequately described and is representative of what is commonly used in clinical practice, (iii) allow for habituation, (iv) minimise risk of bias through appropriate blinding of participants, and (v) measure a range of lower limb biomechanical parameters during walking and running that are clinically relevant in both asymptomatic and symptomatic populations. Importantly, there is also a need to conduct well-designed clinical trials to confirm if the observed biomechanical effects of heel lifts are therapeutically beneficial.

5. Conclusion

Heel lifts affect specific lower limb biomechanical parameters (i.e. decreased maximum ankle joint dorsiflexion and muscle tendon unit length of gastrocnemius) which may be favourable for the management of disorders of the Achilles tendon and posterior lower leg. Further high quality studies are required to investigate the effects of heel lifts on lower limb biomechanics and confirm if these biomechanical effects are therapeutically beneficial.

Author Contributions

Design and conduct of the study: CLR, SEM, HBM
Systematic search and study selection: CLR and GAW
Quality appraisal: CLR and JMT
Statistical analysis and interpretation: CLR, SEM, HBM, AME, JAM
Preparation, review and approval of manuscript: CLR, SEM, HBM, AME, JAM, JMT, GAW

Competing interests

We have read and understood the Gait and Posture policy on declaration of interests and declare we have no competing interests.

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Chantel Rabusin has full access to all of the data in the study and takes responsibility for the integrity of the data and accuracy of the data analysis.

Appendix A. Supplementary data

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